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FAA LORAN EARLY IMPLEMENTATION PROJECT

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Research and Special Programs Administration
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16. Abstract

The Early Implementation Project (EIP), established by FAA Administrator Admiral Donald C. Engen, was the initial step in the process of Loran integration into the National Airspace System (NAS). The EIP was designed to give the FAA and the Loran user community experience in the operational use of Loran. The success of the entire Loran aviation program--particularly the EIP--depended upon the active participation of many organizations inside and outside the FAA. The experience gained in the EIP has helped the FAA make the transition from the limited project to the fully operational system at airports around the country and general users operating with TSO standard receivers. The EIP also serves as a model for the introduction of the Global Positioning System (GPS) into the NAS during the 1990s.

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PREFACE

Loran has progressed from a radionavigation system used almost exclusively by marine interests to a universal system employed by land, sea and air users. This report documents the FAA's initial program to regulate the use of Loran as a nonprecision approach radionavigation aid. The report chronicles the events which led to the establishment of the Early Implementation Project, describes the system configuration and operation and discusses the conclusions and recommendations based on the analysis of data gathered and the operational experience gained by this program.

The authors of this report would like to acknowledge the contributions of all those who have made the Early Implementation Project a success. Since a complete list of contributors is too long to enumerate, we have made a somewhat arbitrary selection of individuals to be mentioned for their special contributions. John Kern (AVS-2) has continuously provided leadership and guidance to the entire FAA Loran program. Jim Enias (AFS-400) and Lyle Wink (AVN-500) have been instrumental in developing standards for the aviation use of Loran. George H. Quinn (ASA-100), FAA Loran program manager, has directed the entire development of the Loran Aviation System. Maurice J. Moroney of TSC's Center for Navigation has been instrumental in initiating the EIP and overseeing its expansion. Paul Burket and John Cornett of NASAO have developed and maintained the interface between the FAA and the Loran user community.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x - 32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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ACRONYM LIST

This list of the acronyms used in this document excludes non-technical abbreviations (such as state codes, commercial designations, and FAA agencies) and terms mentioned only once.

AC	Advisory Circular
AF	Airways Facilities
AFB	Air Force Base
AMMS	Airport Monitor Management System
ASM	Airport Screening Model
AT	Air Traffic
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
AVN	Aviation Standards National Field Office
CDI	Course Deviation Indicator
CONUS	Contiguous United States
db	Decibel
DME	Distance Measuring Equipment
DOS	Disk Operating System
DOT	Department of Transportation
DTS	Department of Transportation Code Designation
ECD	Envelope-to-Channel Discrepancy
EIP	Early Implementation Project
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FAATC	FAA Technical Center
FAR	Federal Aviation Regulation
FS	Flight Standards
FSS	Flight Service Station
FTE	Flight Technical Error
FTS	Federal Telephone Service
FY	Fiscal Year
GDOP	Geometric Dilution of Position
GPS	Global Positioning System
GRI	Group Repetition Interval
ILS	Instrument Landing System
kHz	Kilohertz
LASER	Loran Accuracy, Status, and Error Recorder
Loran	Long Range Navigation
MAP	Missed Approach Point
mb	Megabyte
mHz	Megahertz
MDA	Minimum Descent Altitude
MOPS	Minimum Operating Performance Standards
NAS	National Airspace System
NASA	National Aeronautic and Space Administration
NASAO	National Association of State Aviation Officials
NAVAID	Navigational Aid
NDB	Nondirectional Beacon

NFOLDS	National Field Office for Loran Data Support
nm	Nautical Mile
NOTAM	Notice to Airman
NPA	Nonprecision Approach
OBS	Omnibearing Selector
RAM	Random Access Memory
RNAV	Area Navigation
ROM	Read Only Memory
RSPA	Research and Special Programs Administration
RTCA	Radio Technical Committee of Aeronautics
RWY	Runway
SC	Special Committee (RTCA)
SIAP	Standard Instrument Approach Procedures
SNR	Signal-to-Noise Ratio
STC	Supplemental Type Certificate
TACAN	Tactical Air Navigation
TD	Time Difference
TSC	Transportation System Center
TSO	Technical Service Order
UART	Universal Asynchronous Receiver/Transmitter
USCG	United States Coast Guard
VOR	Very High Frequency Omnidirectional Range
VORTAC	VOR/TACAN Combination

EXECUTIVE DIGEST

INTRODUCTION

The Early Implementation Project (EIP) was conceived as a limited pilot program by Federal Aviation Administration (FAA) to integrate Loran into the National Airspace System (NAS). Long Range Navigation (known by its acronym Loran) has existed since World War II, primarily as a marine navigation system. It has been used by pilots for over-water flights in good weather conditions. The availability of inexpensive airborne receivers spawned a great deal of interest among pilots for using Loran as a navaid, both in the en route environment and as a nonprecision approach (NPA) aid.

The introduction of Loran into the NAS as a radionavigation system represented significant changes in the way the FAA did business. The FAA was faced first with the task of integrating into the NAS a radionavigation system which was not operated by themselves, but by the United States Coast Guard (USCG). Since the USCG used a different set of operating and maintenance procedures, the FAA had to adapt to them or negotiate changes. Second, since Loran was an earth-based system rather than a station-based system, it required adaption to the present air traffic system. The integrity of the Loran signal also required independent monitoring.

The EIP (or "Pilot Monitor Project" as it originally was called) grew naturally out of the Vermont Study Program. Over 200 Loran NPAs were conducted during the study, with Standard Instrument Approach Procedures (SIAP) and approach charts developed by the FAA's New England Region. Given the data from these approaches, the growth of unauthorized Loran RNAV use, and the needs expressed (by state organizations and the user community) for instrument approaches across the United States, the FAA undertook the EIP.

In a memorandum dated July 22, 1985 to the Regional Directors, FAA Administrator Engen established the EIP as an FAA project. This memorandum formally recognized the Loran Working Group set up between the FAA and the National Association of State Aviation Officials (NASAO). It also responded to NASAO's request for a limited Loran implementation project, listing 7 of the 8 participating airports. Since its inception, the Loran Working Group has been a model of FAA, state and industry cooperation. Its quarterly meetings record progress in the EIP; small task forces, such as an education committee and an integrity committee, deal with unresolved issues.

EIP's main issue was improved system integrity. Primary shortcomings in integrity for Loran NPAs for EIP to resolve were:

1. The potential for 60-second delays between unsatisfactory signal conditions and the announcement of the condition. (For certified navaids in the NAS, the FAA requires the system monitor to shut down the source of erroneous signals in less than 10 seconds.)

2. Local area effects, since the USCG only monitors a general area effect.

3. Loran's lack of the Notice To Airman (NOTAM) process, necessary for flight planning.

4. The assurance that local signal conditions were suitable for a safe approach immediately before giving clearance.

In order to deal with these integrity issues, Transportation Systems Center (TSC) installed Loran monitors with support from the monitor manufacturer. Receivers and computers were installed in ATC towers, as were the audio/visual annunciators which relayed Loran status. At each site, dedicated telephone lines enabled remote checks on system status, download data, and upload weekly parameter adjustments. As the installations were completed, approach procedures were developed. Once an historical data base was collected, the FAA performed their flight inspections.

The first FAA-approved instrument approach using the Loran navigation system occurred at Hanscom Field in Bedford MA, at 11:00am on November 4, 1985. The aircraft was a Beechcraft King Air 200, operated by Admiral Donald C. Engen and Sprague Electric's chief pilot.

EIP DESCRIPTION

EIP equipment was used to collect Loran data, monitor the quality of the Loran signals, and determine their suitability for aircraft NPA use. Remote access was provided by a computer phone modem, enabling remote control of the Loran receiver and processing parameters.

The equipment consisted of 3 main parts: a receiver, a general purpose computer and an indicator unit. The monitor computer determines whether Loran system margins are suitable for an NPA within the boundaries of AC 90-45A and if the environment matches or exceeds the minimums set in TSO-c60b. The indicator unit, located in the ATC tower, contains a green and red lamp and an annunciator. The green lamp is lit when the Loran signals are known to meet the quality criteria and the red lamp is lit if the Loran signals are out of tolerance or if there is an equipment malfunction. The annunciator will sound each time the red lamp is lit; its volume can be turned down or off.

Civil instrument approach procedures were developed by the FAA after careful analysis of obstructions, terrain features, and navigational facilities. The most common originators of requests for instrument approach service were NASAO and local commissions and authorities.

Before the commissioning of a Loran NPA, a flight inspection of the approach was conducted by the Aviation Standards National Field Office to determine the suitability of the procedure. Section 209 has been added to the U.S. Standard Flight Inspection Manual AO P 8200.1 describing procedures for Loran NPAs.

The Loran monitor computer is able to store raw data from the receiver for subsequent analysis and archiving. Daily files log the date and time at which there could be any changes in the indicator status or any changes in the reason for red alarm status. Log entries include reasons for any failure, and the latest receiver polled response, if any.

One of the earliest EIP components was a feedback method for pilots to comment on the adequacy of a Loran NPA. Response forms registered pilots' remarks on 311 NPAs. The forms, first issued in 1985, were designed to spur pilot involvement in the program, provide a channel for suggested improvements, and check the accuracy of the correction values.

Pilots reported 11 alarms during approaches and one during an en route section. One flight recorded four alarms before starting an approach, three of 10 seconds duration and one of 5 seconds. Though 7 other alarms resulted in missed approaches, the status of the airborne receiver and the monitor receiver were always in agreement. There were no incorrect cycle acquisitions reported. Areas of good Loran signal-to-noise and good geometry are an adequate safeguard from incorrect cycle acquisition.

Although it originally was planned to operate the EIP for one year, that time frame increased and the only practical means of accommodating more users was to expand the EIP. With the number of monitors purchased for the EIP fixed at 10, monitors had to be moved from inactive sites to central locations which served multiple landing sites. The two main levels of location for Loran monitors are as follows:

1. ATCTs: Alarms are processed at a real time rate of less than 10 seconds at the clearance delivery point.

2. AFSSs and FSSs: Alarms are processed in quasi real time. FSS operators must call the clearance delivery point at the ARTCC.

DATA ANALYSIS

The EIP monitors serve a dual function: they provide indicators of Loran signal integrity and act as a medium for collecting data on signal quality and accuracy, as well as the operational characteristics of the entire Loran transmitter system. While supporting NPAs, the monitors gave the FAA the added opportunity to develop a data base of Loran information from several locations nationwide. This data base helped shape Loran policies.

The EIP hardware is designed to alarm when the signal characteristics exceed predetermined limits. The limits are conservative. As operational experience was acquired, alarm limits were varied and data collected to assess impacts of the changes on alarm frequency and work load. Experience with the EIP unit guided the design of the operational monitor.

One additional software change caused distance violations to be recorded in the snapshot file with 1200 additional seconds of data after the event. This permits a complete assessment of the extent of a distance violation. It answers the question, "How far did the signal drift from the center line?" The integrity issue which the FAA has been forced to address is the possibility of the so called "slow TD drift." The problem is that of large variation of TD due to changes in the propagation path at far distances from the USCG monitor. The positional errors which these TD variations produce would not be detectable either by the USCG or in the cockpit. The EIP monitors were designed to produce alarms whenever the position determined by the TDs was outside the proscribed limits.

The EIP software identified 51 violations as distance since the software modification was installed in January, 1989. Ten cases were alarms initiated for other reasons which extended into the following hour and were inadvertently designated on the hour as distance by the software. Analysis of the rest of the distance alarms showed them to be attributable not to propagation effects but rather timing errors at the transmitter or monitor malfunctions. In all but 2 cases, alarms initiated by distance violation suggested a transmitter status condition (such as blink) a short time into the alarm. There were no indications of "slow TD drift."

In 1989, there were 9 months of data from 7 monitors and 6 months from another. The monitor in the South Bend FSS stopped recording data on July 4, 1989 and was removed in August. The 8 monitors logged 7096 alarms. Transmitter operation alarms (58% or 4094), can be reduced by changes in transmitter operation or in monitor software. Noise in the area caused 27% of the alarms (1894). Loss of power was not a problem; no FSS monitors had power outages. All power outages recorded in 1989 came from Orlando and were induced by the TSC operator. Though the abovementioned distance alarms accounted for 51 events, none of them were real. The other (812) events were caused by TSC operators during normal

system maintenance. Careful analysis and system modification have reduced the number of alarms from more than 24 to 4 per day per site with no decrease in the level of safety.

The present USCG policy is to consider any signal interruption of less than 60-second duration as a momentary and not to count it in the signal availability calculation. Typically a station's transmit performance is 99.953 percent with 19 minutes per month unusable, with reasons recorded for the unusable time (e.g., power failure). The control performance is typically 99.993 percent with 3 minutes per month unusable, with reasons recorded for the unusable time (e.g., control watchstander error.) Momentaries also are recorded and summarized in USCG monthly reports.

The EIP staff analyzed 6 months of status alarms from the monitors watching signal performance of the Northeast Chain. The analysis of the duration of the events indicated that most were caused by transmitter momentaries (events of less than 60 seconds). In most cases, transmitters and monitors recovered within 30 seconds of first detecting an out-of-tolerance event (76% of status events lasted less than 27 seconds). Events longer than 60 seconds were: scheduled by USCG; unscheduled and off-air; or identifiable by a blink status.

Analyzing the data shows momentaries cause a complete loss of signal at the monitor sites. This suggests that if a momentary is detected there is no requirement for the FAA's operational monitors to go into an out-of-tolerance state and require a notification of Air Traffic. This type of alarm will be detected by aviation receivers that meet the standards in TSO-c60b, "Airborne Area Navigation Equipment Using Loran C Inputs".

The critical discovery in the operation of the Loran transmitting system is the need to blink the system when it is operating outside specified values. Current operating procedures require the watch-stander to observe the signal for one minute before taking corrective action. TD limits are 0.10 to 0.15 microseconds. These limits are conservative, but the one minute delay time is critical. The FAA requires the generation of a blink signal in 10 seconds whenever the signal drifts beyond 0.5 microseconds. The FAA does not permit an NPA in an area with a GDOP of 3000 feet/microsecond. A 0.5 microsecond absolute limit insures either that an aircraft using the Loran signal will be within the protected corridor or the signal will be blinking.

The conclusion was reached that local area effects of the Loran signal were constant up to a radius of 90 nm, or an area of approximately 25,447 square nm. On that basis, the FAA purchased 196 Loran monitors for CONUS and Alaska. This 90 nm radius was supported by the 10-monitor network deployed across the CONUS in the EIP. Other supporting sources included the Ohio University operation of 2 monitors on a 92 nm baseline, ARNAV Inc.'s two

receivers on an 85 nm baseline in Oregon, and the FAATC airborne data collected by flying 6 flight paths across CONUS.

CONCLUSIONS AND RECOMMENDATIONS

The EIP has been the FAA's means of introducing Loran into the NAS safely and efficiently. The experience gained through this project has enabled the FAA to plan effectively for the full scale implementation of Loran as well as GPS. The following are the principal conclusions which can be drawn from this report.

a. A program which introduces new technology and procedures into the NAS can benefit by a limited pilot project like EIP; both the FAA and Loran users can gain experience in the operation and limitations of the system. The active involvement of outside groups such as NASAO and avionics manufacturers should be encouraged.

b. There is no need for real time monitoring of the Loran signal by the FAA. Four years of EIP data collection have shown no evidence of the "slow TD drift." Unless some anomalous propagation behavior is manifested at a new site by the operational Loran monitor network all alarm conditions can either be detected in the cockpit or by the USCG monitor network.

c. With minor modifications, the 56-day TD forecast algorithm utilized by the EIP can work for NPA corrections with the data collected by the operational Loran aviation monitor system.

d. The alarm history of the EIP shows the necessity for a special USCG aviation blink procedure, preferably automated, in order for there to be widespread aviation use of Loran NPAs. The integrity requirements demand an immediate blink when aviation tolerances are exceeded.

The EIP, initiated in 1984, was the first step in the process of Loran integration. Today Loran is the established and accepted supplementary system for en route movement. It is also the basis for the current FAA program to open to NPAs many of the 17,000 landing sites which are not programmed otherwise for instrument-aided approaches. The EIP gave the FAA and the Loran user community experience using Loran. Success of the Loran aviation program (particularly the EIP) depended upon active participation of organizations inside and outside the FAA, with state officials acting through NASAO making major contributions. NASAO took the Loran message to their respective states. They identified users, classified 500 airports for the first set of Loran RNAV NPAs, and continue to provide leadership in acquiring congressional support for Loran.

This report recommends that the FAA/NASAO Loran Working Group carry on its efforts to bring a new vision to air navigation. Loran is already widely used and accepted as the official supplementary navigation aid. The first successful launches of the GPS satellite configuration have taken place. However, studies show conclusively that GPS cannot provide the signal availability and integrity needed to meet stringent sole-means aviation criteria, even with satellites positioned and functioning. It may be possible for the two systems to be complementary and provide sole-means 3-dimensional coverage. If studies determine that this route is feasible then no doubt it will also require large financial expenditures and involve extensive politics. NASAO adequately fills this role. New standards for Loran, GPS and their components will be developed to make system costs affordable and their implementation effective.

Loran receiver manufacturers contributed much technical expertise to the program. It is a long time policy to capitalize on the experiences of the aviation community (users, receiver manufacturers, FAA representatives) when avionics need standardization. In the EIP they produced "RTCA/DO-194 Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Loran-C Inputs" in November 1986. The document includes standards for equipment characteristics useful to designers, manufacturers and installers. It defines performance functions and features of Loran systems for en route, terminal and approach modes.

This report recommends that the Loran Working Group be expanded to include technical expertise from the GPS area. This group would guide a requirements study for a mutually supportive system. It also recommends the development of a comprehensive plan for the navigation system for the 21st century. In February 1983, the Office of Flight Operations of the FAA sponsored a 2-day conference of Government experts to develop the initial criteria for Loran approaches. The conference recognized the need to deal with the overriding issues of signal integrity, system performance assurance, and airworthiness standards. The FAA should convene a conference of Government experts to develop the initial criteria for the comprehensive plan.

1.0 INTRODUCTION

The Early Implementation Project (EIP) was conceived as a limited pilot program by Federal Aviation Administration (FAA) to integrate Loran into the National Airspace System (NAS). Long Range Navigation (known by its acronym Loran) has existed since World War II primarily as a marine navigation system and has been used by pilots for over-water flights in good weather conditions. The availability of inexpensive airborne receivers spawned a great deal of interest among pilots for using Loran as a navigational aid, both in the en route environment and as a non-precision approach (NPA) aid. It didn't take long for Loran receivers to become one of the fastest selling pieces of avionics equipment. Reasons for the increased interest were several: the development of miniature circuitry and microprocessors led to the manufacture of smaller, lighter, and ultimately less expensive airborne receivers.

The FAA began to formulate plans to regulate the use of Loran. The introduction of Loran into the NAS as a radionavigation system represented significant changes in the way the FAA did business. The FAA was faced first with the task of integrating into the NAS a radionavigation system which was not operated by themselves, but by the United States Coast Guard (USCG). Since the USCG used a different set of operating and maintenance procedures, the FAA had to adapt to them or negotiate changes. Secondly, since Loran was an earth-based system rather than a station-based system, it required adaption to the present air traffic system. Additionally the integrity of the Loran signal required independent monitoring.

The EIP, established by FAA Administrator Admiral Donald C. Engen, was the initial step in the process of Loran integration. The EIP was designed to give the FAA and the Loran user community experience in the operational use of Loran. The success of the entire Loran aviation program and particularly the EIP depended upon the active participation of many organizations inside and outside the FAA.

The EIP began to pay off as each organization contributed to making the project a resounding success: Flight Standards (FS) established approach procedures and approved receivers; Air Traffic (AT) incorporated Loran Approaches using the monitor annunciator for integrity; the Navaids Branch of the Navigation and Landing Systems Division provided program management. The FAA sought and received aid from outside sources; notably, officials acting through the National Association of State Aviation Officials (NASAO) made major contributions by soliciting users for NPAs. Loran receiver manufacturers contributed much technical expertise to the program.

This report presents the elements which made the EIP a model for similar programs, such as the anticipated introduction of the Global Positioning System (GPS). The chronology of the project (Section 2) illustrates the program flow and points out the motivation behind some of the decisions made along the way. Section 3 presents a complete description of the EIP, both in its initial configuration and subsequent modifications. Section 4 is an analysis of data collected during the lifetime of the EIP. Section 5 describes the impact of the EIP on other related programs. Section 6 reports conclusions arrived at during the EIP experience, and Section 7 lists the authors' recommendations.

2.0 CHRONOLOGY OF EIP

This section traces the history of the EIP from its beginnings. Loran's role in aviation, strictly speaking, predates most of the EIP activity. This chronology, however, covers only the efforts required to establish approved Loran aviation procedures. The project has many threads starting from the Vermont Study Program and continuing to the present. Also described are the program flow and the cooperative effort on the part of many participants inside and outside the federal government.

2.1 Vermont Study Program

In 1977, the Vermont Department of Aeronautics presented the Department of Transportation (DOT) Office of the Assistant Secretary for Research and Technology--forerunner of Research and Special Programs Administration (RSPA)--with an informal request to help improve air access to Vermont's low altitude airspace and airports. At that time, the influx of new businesses to Vermont communities was creating a demand for improved airline, air taxi, and business aircraft services which could not fully and efficiently be met with the present limitations in navigation and approach aids.

There are 19 public-use airports in Vermont. The city of Burlington owns and operates one. Ten are state-owned and maintained, but are run by fixed-based operators through leasing arrangements. The remaining 8 airports are privately owned.

Except for Burlington International Airport, none of the state or privately owned airports had either precision approach or terminal area radar service. While 8 of the 10 state airports do have FAA-approved NPAs, only 3 include localizers. The remaining 5 rely upon either Very High Frequency Omnidirectional Range (VOR) or Nondirectional Beacon (NDB) approaches. The result is an unsatisfactory history of cancellations or delays at all but Burlington, where weather conditions often force arriving traffic to use runways other than those serviced by Instrument Landing System (ILS).

Some of these airports require the use of circling criteria with their attendant higher minima. High terrain, which interrupts line of sight signals from VORs, limits low altitude, en route, and terminal area operations. At only 4 airports in Vermont can pilots use VOR signals below 3000 ft. mean sea level.

In 1974 the Vermont Department of Aeronautics was made aware of the potential for Loran to provide the navigation and guidance capability necessary for operation in mountainous terrain. To support Vermont's expressed interest, the USCG conducted a week-

long series of demonstration flights in a Loran-equipped C-110 aircraft. Low altitude en route, terminal area and approach operations were successfully proved at several mountain-bound airports. These activities ultimately led to Vermont's informal request for help from the DOT/RSPA. The Transportation System Center (TSC) was to conduct an extensive, scientifically credible evaluation of Loran Area Navigation (RNAV) to complement the existing system of FAA-provided aids and procedures and remove some of the existing operating restrictions.

At that time, developments in Loran ground-based and air-borne equipment offered an opportunity to meet some of Vermont's operational and technical needs within a reasonable period of time and without requiring major capital expenditures.

RSPA, FAA, and the National Aeronautic and Space Administration (NASA) Langley Research Center joined forces with Vermont's Agency of Transportation to plan and execute the Loran evaluation program. RSPA, with primary responsibility for general program coordination, designated TSC as the program manager in charge of design of experiments, basic field measurements, data analysis, and report preparation.

The FAA New England Regional Office designed Loran NPAs to 8 runways at 4 airports, and reviewed performance data as it became available. The Regional Office also determined the acceptability of the Supplemental Type Certificate application submitted by Vermont to request authorization to operate Loran RNAV in Twin Beech aircraft.

NASA/Langley designed, fabricated, installed, and calibrated the data collection instrumentation. Langley personnel also prepared the software necessary to process the flight and ground-based data records.

Vermont's Agency of Transportation conducted engineering surveys of selected locations and supplied flight crews, aircraft and avionic maintenance personnel. Technical and operational support was provided to the Agency by Polhemus Associates Inc., a Vermont based company.

Flights were conducted during visual and instrument meteorological conditions, at day, night, and twilight hours, through 4 seasons using the primary and alternative triads of the Northeast Loran chain. In support of the flight program, the Loran signal characteristics measured at 4 ground monitoring sites in Vermont over an 18-month period determined electromagnetic compatibility, predictability, temporal stability, and the availability of signals for airborne navigation.

During the data collection period, from July 1979 to October 1980, the Twin Beech completed 160 en route, 105 terminal or

transition segments, and 215 NPAs. Visual observations of the cross track and along track errors were made on every approach segment and, weather permitting, on all transition and en route segments. Precision measurements of the errors were made on segments from 33 flights which included 66 en route and 101 terminal segments and 76 NPAs. Evaluation of more than 46,000 measurements of the aircraft's position quantified the accuracy of the Loran RNAV system.

During the test period, 76 approaches were flown on the precision test range. Scheduled NPAs were made to 8 runways at 4 airports. Analysis of test data from the flights proved compliance with the requirements listed in the advisory document. The mean-plus-two standard deviations of total system cross track error was 0.32 nm--far less than the AC90-45A value of 0.6 nm.

On October 9, 1981, the FAA New England Region Office issued the first Supplemental Type Certificate (STC) for the use of a Loran navigator for en route navigation in the NAS. The STC was awarded to the State of Vermont for a Twin Beech Model E50 aircraft using a Teledyne TDL-711 navigator. The award signified the successful completion of a cooperative research program to evaluate Loran's capability of satisfying en route, terminal, and NPA accuracy requirements.

Vermont continued the certification process to remove limitations and extend the coverage to terminal and approach operations. The test data base was big enough to justify this effort. The final report documents the suitability of the Loran navigation system in the current NAS environment. No degradation in navigation accuracy or aircraft performance was observed when the Loran system was compared with the VOR/DME system.

2.2 The Role of NASAO in the EIP

As more and more aviators sought to use Loran for en route navigation and NPAs, the FAA had to come up with more concise rules and regulations to govern use of the system. Some of the areas were: designating approach site parameters; approval of receiver design; installation and flight inspection procedures; and conditions for aborting NPAs.

In 1983 state aeronautical organizations started voicing the need to implement FAA-approved Loran RNAV procedures, including terminal area instrument departures and NPAs. They envisioned Loran filling the void in instrument approaches at public and private landing facilities at extremely low system costs and relatively low user cost. The FAA began receiving many proposals and offers of assistance to develop programs and procedures for expanded utilization of the Loran system. These proposals expressed the need to verify Loran signal performance by use of

monitors installed at selected locations nationwide and to add transmitters to extend coverage throughout the contiguous United States (CONUS). In February 1983, the FAA's Office of Flight Operations sponsored a two-day conference of government experts to develop the initial criteria for Loran NPAs. The conference began to deal with the overriding issues of signal integrity, system performance assurance and airworthiness standards.

Early 1984 dialogue between the FAA and both state and user organizations progressed without the FAA making a full commitment to Loran as a RNAV aid. FAA studies continued toward setting a national aviation standard for Loran. The FAA--through the Radio Technical Committee for Aeronautics Special Committee 137 (RTCA SC-137)--was working on Minimum Operation Performance Standards (MOPS) for Loran avionics. The FAA soon initiated a program to evaluate and demonstrate the use of Loran as a navaid for NPA.

The FAA Administrator, Admiral Donald C. Engen, recognized continued increases in Loran usage and its value as an aviation navigation supplement to VOR/DME for low altitude, offshore, and direct flight navigation. He identified significant issues to be addressed before the FAA made a complete commitment to Loran: positional variation due to seasonal conditions and their effect on the safety of NPAs; the limiting effect of the mid-continent gap (area lacking Loran coverage in the middle of the CONUS); and the impact of the advent of GPS.

By September 1984, the FAA was fully committed to the development of Loran as an RNAV aid with complete CONUS coverage. Engen presented the FAA's policy revision to the Secretary for Budget and Programs and requested additional funding for Loran. His letter stated:

> **The policy revision will establish Loran-C as an interim, supplemental radio navigation system for aviation use, will advocate the completion of Loran-C coverage so there is at least single level coverage for all of the contiguous United States, and will set the criteria for the establishment of Loran-C NPAs.**

In February 1985, the Ohio Department of aviation hosted a 2-day workshop on Loran NPA at Columbus. The head of the NASAO Loran Task Force, Paul Burket of the Oregon Aeronautics Division, extended invitations to key FAA officials. The workshop developed into an informal working and planning group consisting of FAA personnel, state officials, and industry and university representatives. The plan for a pilot project consisting of 4 to 8 monitored landing sites was developed, and recommendations for accelerating the Loran program and increasing the role of NASAO were forwarded to the FAA.

In a memorandum dated July 22, 1985 to the Regional Direc-

tors, Administrator Engen established the EIP as an FAA project. This memorandum formally recognized the FAA/NASAO Loran Working Group and responded to the NASAO request for a limited Loran implementation project. Engen delegated responsibility to NASAO (user selection and public relations) and to key FAA personnel. The memorandum also listed 7 of the 8 airports in the project. A meeting of the Loran Working Group followed (July 24-25) at NASAO Headquarters in Washington. NASAO conducted a demonstration flight using Loran for observers from the FAA, USCG, RSPA, Congress and the public.

Since its inception, the Loran Working Group has been a model of FAA, state and industry cooperation. Its quarterly meetings record progress in the EIP; small task forces, such as an education committee and an integrity committee, deal with unresolved issues.

2.3 The First Eight Loran NPAs

The EIP (or "Pilot Monitor Project" as it was originally called) grew naturally out of the Vermont Study Program. Over 200 Loran NPAs were conducted during the study, with Standard Instrument Approach Procedures (SIAP) and approach charts developed by the FAA's New England Region. Given the data from these approaches, the expansion of unauthorized Loran RNAV use, and the needs expressed (by state organizations and the user community) for instrument approaches across the United States, the FAA undertook the EIP. This section outlines Phase 1 events: the implementation of EIP and installation of the first 8 monitors.

October, 1984 brought the commitment of private industry (Sprague Electric Company of Lexington, MA) to the study of Loran NPAs. A meeting at North Adams Harriman and West Municipal Airport between officials from the Massachusetts Aeronautics Commission and Sprague mapped out objectives for the study. Sprague agreed to sponsor a Massachusetts approach by its aircraft, already equipped with Loran receivers, and to suggest an airport for the study.

With Sprague's commitment, the FAA completed a program proposal for FY85-FY86, defining the principal issues of EIP, suggesting resolutions, and delegating responsibilities for its operation. EIP's main issue was improved system integrity. Primary shortcomings in integrity for Loran NPAs that EIP had to resolve were:

1. The potential for 60-second delays between unsatisfactory signal conditions and the announcement of the condition. (For certified navaids in the NAS, the FAA requires the system monitor to shut down the source for erroneous signals in less than 10 seconds.)

2. Local area effects, since the USCG only monitors an overall area effect.

3. Loran's lack of the Notice To Airman (NOTAM) process, necessary for flight planning.

4. The assurance that local signal conditions were suitable for a safe approach immediately prior to giving clearance.

The proposal for resolving these issues read:

> **The FAA should, during 1985 and 1986, establish Loran special NPAs at 4 airports currently served by other aids. Operators should be given approach authority through special letters of authorization. The terms and conditions of the letters of authorization could include such items as:**
>
> **1. Monitoring of navigation systems described in the FAR Part 97 SIAP is required.**
>
> **2. Two pilots required.**
>
> **3. Pilot report of observed signal accuracy required after each operation.**
>
> **The effort should include a data collection/analysis program which uses results of the operations at these 4 test airports to develop precision approaches at airports not served by any other navigation signal. The factors to be considered include flight inspection requirements, ATC communications requirements, airworthiness/operations certification standards, etc.**

The proposal delegated data gathering and analysis to TSC and the following implementation responsibilities among several FAA agencies:

ADL: (AES-300/APM-400): To deploy 4 monitors at 4 airports selected by AVS (AFO-200 & AVN-200) in cooperation with ADL and AAT (ATR-100/ATO-300).

ADL: To conduct detailed data collecting flights at all the selected airports at least once a quarter, using the FAA Technical Center (FAATC) Loran test aircraft.

AVN: To conduct operational evaluation flights at similar intervals using flight inspection aircraft.

ADL: To gather and analyze data (from user feedback, moni-

tors, flights) with support from TSC, and to propose final implementation criteria.

AVN: To prepare a Loran SIAP which overlays an existing SIAP at each airport.

AFO: To issue letters of authorization, through regional district offices, to applicants based on conformance with criteria to be developed by AFO-200, AVN-200 and AWS-100/300.

AAT: To issue clearances for Loran operations based on a determination that a given monitor is displaying a satisfactory condition.

ATR-100, AES-300, AFO-200 and AVN-200 are to actively participate in the deliberations of RTCA SC-137 and to review current NAS Plan programs for effectiveness in improving earth reference navigation systems.

Once the FAA had established the Loran program, it created a schedule for the EIP Phase 1 implementation and presented it at the first Loran Workshop (see Section 2.2.)

Program setup	April 10, 1985
Implement test procedures	May - June, 1985
Gather data	June - October 1, 1985
Implement improvements	FY86
Publish national plan	FY87

The FAA stated the purpose of EIP Phase 1 as building confidence in the system and establishing its operational capability. The FAA intended to complete Phase 1 by October to better proceed with full implementation. The workshop also established the need to expand Phase 1 from 4 to 8 airports.

2.3.1 Equipment Delivery Schedule

By March 1985, the equipment requirement was established and presented to the FAA/TSC with the initial delivery schedule. Given here is the schedule and a brief description of the equipment; a more detailed examination of the equipment and its software is given in Section 3.

April 15: Complete the first monitor unit to meet the primary requirement of control of indicator box.

April 30: Deliver the first unit with software, including remote command and remote monitoring capability.

May 7: Deliver new software which creates the log file

and its downloading capability.

May 21: Deliver software which creates the average data files, snapshot files, and downloading capability.

June 7: Deliver units 2-5 complete.

July 7: 4 installations complete.

2.3.2 Equipment Description

Loran Receiver:	Megapulse Accufix 500 Loran rèceiver with antenna, antenna coupler and cable.
CPU:	IBM-PC compatible with MS-DOS. Programs written in C and Assembly language.
Indicator encoder:	Custom-made PC board.
Indicator Unit:	Red/Green light unit with warning buzzer to be located in the Air Traffic Control Tower (ATCT).

2.3.3 FAA Region Briefings

On April 17, the first monitor was installed at Hanscom Field in Bedford, MA and the EIP was on its way. FAA officials began visiting regional offices, bringing their staffs up to date on Loran. The step by step process of these briefings was:

1. The Loran Project Engineer (APM-420) contacts the staff of the Regional Airways Facilities (AF) Division Chief.

2. The AF Chief organizes a meeting and invites FS, Air Traffic (AT), and Airports Division.

3. Project engineers brief the region on:
   a) FAA policy and plans for Loran
   b) Technical details on how Loran works
   c) Implementation of Loran in the region.

4. Project engineers brief AF Sector Chief.

5. Project engineers go to ATCT to brief AT Chief and AF Unit Chief. Each briefing level, from the region on down, becomes more technical and hardware oriented.

6. The team briefs users on their responsibilities.

7. FS schedules and briefs users and the Airport District Office on Technical Standard Orders (TSOs) and MOPS.

By July 1985, two of the monitors were installed and all but one of the airports were picked (see Table 2-1). State officials had identified, at each airport, users who already had or were willing to install approved Loran receivers in their aircraft and who would apply for an STC for NPAs (see Table 2-2.)

Monitors were installed by TSC and local AF personnel with support from the monitor manufacturer (see Figure 2-1.) Receivers and computers were installed in ATC towers, as were the audio/visual annunciators which relayed Loran status. Antennas and couplers were generally placed on the tower's roof. Initial setup parameters (Time Differences (TDs)) were derived by the FAA's Loran Airport Screening Model and updated with onsite measurements. Local electromagnetic interference frequencies were identified with a spectrum analyzer and blocked out with additional notch filters. At each site, dedicated telephone lines enabled TSC's remote checks on system status, download data, and upload weekly parameter adjustments. The Beaumont, TX site (installed July 1985) was transferred to Lakefront, LA because it lacked sufficient Loran coverage to support an NPA. As the installations were completed, approach procedures were developed. After several months of data collection, the FAA performed flight inspections (see Table 2-3).

With Phase 1 of the EIP the FAA reached its full project objectives, including gaining operation experience with Loran; approving methodology for Loran receiver installations in aircraft; developing approach procedures and formulating standards and operations applicable to (or in agreement with) all supplemental navigation aids.

As Loran expanded, the potential for aviation applications increased. With the FAA's strong support for this program, 7 more runways since Hanscom Field were added. At this point, 6 states were involved (Massachusetts, Florida, Ohio, Oregon, Texas and Vermont), and more interested in participating.

2.4 The First Nonprecision Approach

The first FAA approved instrument approach using the Loran navigation system occurred at Hanscom Field in Bedford MA, at 11:00am on November 4, 1985. The aircraft was a Beechcraft King Air 200, operated by Admiral Donald C. Engen and Chief Pilot Alan Isherwood of Sprague Electric. The inaugural approach plate was sent to the Smithsonian Institute (see Figure 2-1). The flight scenario went like this:

10:58am N275SE contacts ground control at Hanscom Field and gets taxi clearance to Runway 11

10:59 N275SE changes contact to Hanscom Tower and requests Runway 11 for take-off and Loran NPA

11:02 Tower puts N275SE into hold position on Runway 11

11:03 N275SE cleared for take-off on Runway 11

11:04 Departure complete

11:05 Course instructions and contact with Boston departure and approach

11:07 Course change

11:09 Course change

11:10 Course change: 1 mile west of lobby (final approach)

11:12 N275SE contacts Hanscom Tower to request clearance on Runway 11 for Loran NPA

11:15 Tower gives final clearance and fix; craft is 4 miles out on final approach

11:17 Touchdown!

11:18 N275SE contacts ground control and taxis to park.

Inaugural flights for the other 7 sites took place in 1986 (see Table 2-3).

2.5 Implementation of Full Scale Program

The EIP was a pilot project leading to the full-scale implementation of Loran as a radionavigation system in the NAS. Long-range planning began at the outset of the EIP. FY87 funds were provided to purchase the 4 Loran transmitters needed to fill the Loran CONUS gap and 212 operational monitors.

2.6 EIP Expansion

Experience gained from the EIP demonstrated the need to gather more data before the full scale system could be operational. The EIP was structured to provide enough flexibility to the project so that it could support expansion beyond the original 8 airports before the operational system came on line. The general constraint to expansion was a fixed number of available monitors. There was demand for additional NPAs as well as cessation of operations by approved Loran users.

2.6.1 Non-collocated Monitor NPAs

The first Loran NPA (i.e., where monitor and airport are not collocated) took place in Venice, LA at the Chevron heliport in April, 1988. The NPA filled a need for an IFR approach to bring increased access to the area. EIP monitors helped establish the site as a viable location for Loran NPAs.

The question facing the FAA was whether TD values for Venice could be forecast with an acceptable error using data from the Lakefront EIP monitor located approximately 60 miles away. The FAA requested TSC install an EIP monitor unit at Venice, which collected data for 6 days (May 28 thru June 2nd) including the TDs from the 7980 MWX triad. This data was compared and analyzed (see Section 4.1) with data collected at Lakefront during the same period. Analysis showed that Lakefront and Venice variations match, with errors in tens of nanoseconds. This demonstrates that Lakefront could adequately predict the Loran signals at Venice with an adjustment in Lakefront's monitor error budget.

2.6.2 Non-Tower Locations Of Loran Monitors

Loran monitors were originally located in ATCTs at the landing sites. In order to accommodate a larger number of approaches with a fixed number of monitors and maintain the real time monitoring function, some monitors were relocated to Flight Service Stations (FSSs) in South Bend IN, Utica NY, Millville NJ, and Leesburg VA. It should be noted that locating monitors at FSSs allows Loran approaches to be developed for non-towered airports. TSC maintains its own Loran monitor in Cambridge, MA for data collection and software development.

2.6.3 Non-monitored NPAs

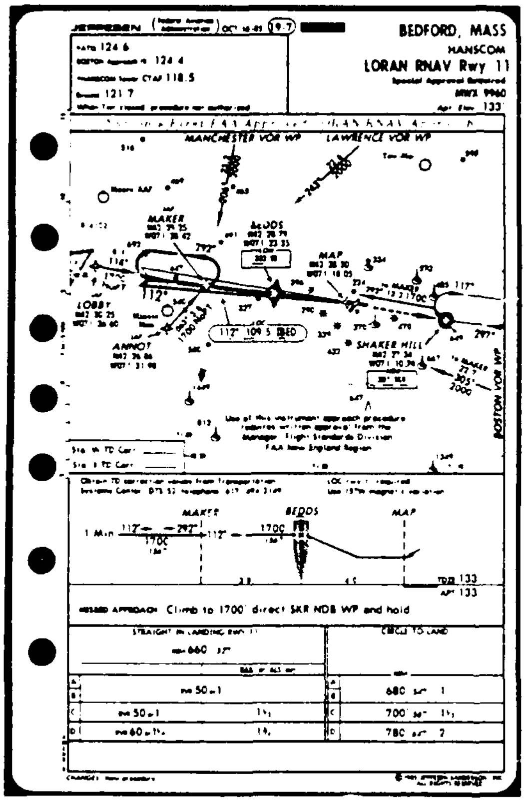
On August 17, 1988, Reeve Aleutian Airways demonstrated to the FAA Safety Inspector that the Chief Pilot was able to make NPAs using Loran signals for guidance at Amchitka Island, AK, in the Aleutian Chain. The fogbound Aleutian Islands are a barren 1,000-mile archipelago dividing the Bering Sea from the Pacific Ocean. The islands are the meetingplace of the cold arctic air and the warm, moist air of the Japan current--a phenomenon that spawns fog and bitter winter weather. Their isolation make the Aleutians difficult to visit; scheduled air service reaches few towns. Loran NPAs provided a useful supplemental navaid. The approved Loran IFR NPA to Runway 25 at Amchitka was the first Loran NPA not guarded by a FAA monitor. After this successful NPA, the Chief Pilot of Reeve Airways was authorized to train his pilots to use this NPA on weekly flights to Amchitka.

Figure 2-1. EIP Inaugural Approach Plate.

US Department of Transportation
Federal Aviation Administration

First FAA Approved LORAN-C IFR Nonprecision Approach.

November 4, 1985



Flight Members

Donald D. Engen
Robert E. Whittington
Louis W. Roberts
[illegible]
[illegible]
Norman J [illegible]
[illegible]
William J Bleil
Alan W. [illegible]
Arnold R. [illegible]

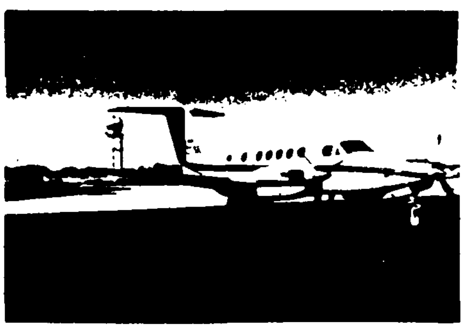


Table 2-1. Data on Initial EIP Airports.

NAME	CITY, STATE	AIRPORT LAT, LONG	CHAIN TRIAD	AIRPORT TD'S	CROSSING ANGLE
L.G. HASCOM FIELD	BEDFORD, MA	42 27' 54" 071 17' 21"	9960 MWX	14117.970 26028.290	123.58
PORTLAND INTL	PORTLAND OREGON	45 35' 19" 122 35' 52"	9940 MWX	12247.470 28153.900	63.54
MANSFIELD LAHM MUNI	MANSFIELD OHIO	40 49' 17" 082 31' 00"	9960 MYZ	43342.230 56888.780	126.37
LAKEFRONT	NEW ORLEANS LOUISIANA	30 02' 34" 090 01' 42"	7980 MWX	11573.830 28713.380	145.10
OHIO STATE UNIVERSITY	COLUMBUS OHIO	40 04' 48" 083 04' 24"	9960 MYZ	42927.290 56425.390	118.17
BURLINGTON INTL	BURLINGTON VERMONT	44 28' 17" 073 09' 11"	9960 MWX	14224.450 27259.190	41.37
ORLANDO EXECUTIVE	ORLANDO FLORIDA	28 32' 44" 081 19' 59"	7980 MYZ	44355.840 62320.960	121.51
MCNARY FIELD	SALEM OREGON	44 54' 35" 123 00' 10"	9940 MWX	12663.550 28076.090	65.46

Table 2-2. Initial Users of Loran EIP.

NAME	NAV REFERENCE	RUNWAY	CHAIN TRIAD
L.G. HASCOM FIELD	ILS	11	SPRAGUE ELECTRIC
PORTLAND INTL	ILS	10R	LAMB-WESTON
MANSFIELD LAHM MUNI	ILS	32	STATE
LAKEFRONT	ILS	18R	CHEVRON
OHIO STATE UNIVERSITY	ILS	09R	STATE
BURLINGTON INTL	ILS	15	NORTHERN AIRWAYS
ORLANDO EXECUTIVE	ILS	07	STATE
MCNARY FIELD	ILS	31	LAMB-WESTON

Figure 2-2. Typical EIP ATCT Installation.

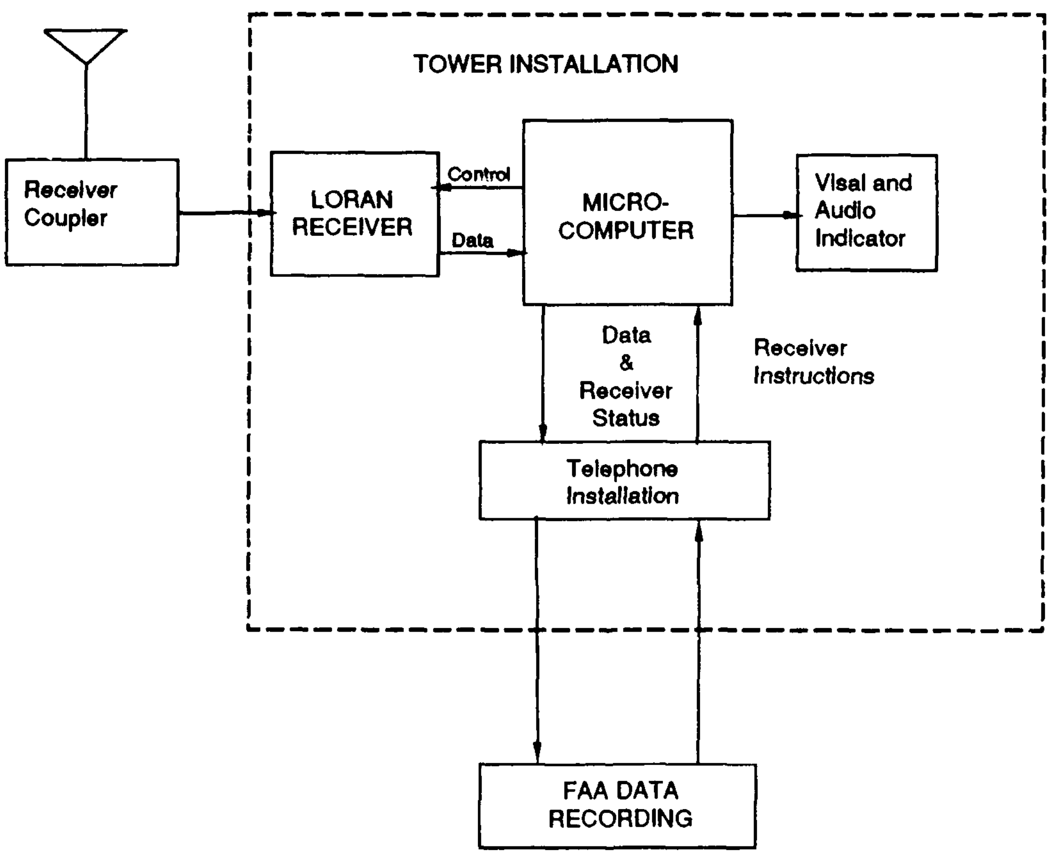


Table 2-3. EIP Flight Inspection Data.

AIRPORT NAME	MONITOR INSTALLATION DATE	APPROACH PROCEDURES COMPLETED	FLIGHT INSPECTION COMPLETED	INAUGURAL FLIGHT
L.G.HANSCOM	APRIL 17, 1985	OCT 27, 1985	SEPT 25, 1985	NOV 4, 1985
PORTLAND INTL	JUNE 13, 1986	OCT 27, 1985	DEC 18,1985	MAY 30, 1986
LAKEFRONT	MAR 15, 1986	MAR 15, 1986	OCT 10, 1986	OCT 21, 1986
OHIO STATE UNIVERSITY	AUG 12 1985	OCT 27, 1985	MAR 27, 1986	OCT 6, 1986
BURLINGTON INTL	SEPT 11, 1985	OCT 27, 1985	SEPT 25, 1985	FEB 11, 1986
MCNARY FIELD	OCT 7, 1985	OCT 27, 1985	DEC 17, 1985	MAY 30, 1986
MANSFIELD LAHM MUNI	NOV 15 1985	NOV 27, 1985	MAR 27, 1986	DEC 18, 1986
ORLANDO EXEC.	DEC 15, 1985	MAR 15, 1986	MAR 26, 1986	MAY 22, 1986

3.0 EIP DESCRIPTION

Loran NPAs have been executed routinely under the EIP using equipment and procedures specifically designed for this purpose. Section 3 describes in detail the EIP, including the design of the monitor and the development of the operational procedures. This section also describes the enhancements added to the EIP as the project matured.

3.1 EIP Equipment

EIP equipment was used to collect Loran data, monitor the quality of the Loran signals, and determine their suitability for aircraft NPA use. Remote access was provided by a computer phone modem, providing remote control of the Loran receiver and processing parameters.

The equipment consisted of 3 main parts: a Loran receiver, a general purpose computer and an indicator unit. The receiver and computer are separate assemblies mounting in a standard 19-inch rack with a keyboard interface. The indicator unit, located in the ATC tower, contained dual red and green lamps plus an annunciator. (Green lamps were lit when the Loran signals were known to meet the quality criteria. Red lamps were lit if Loran signals went out of tolerance or during an equipment malfunction. The buzzer sounds each time the red lamps first come on.)

The receiver and computer were installed in a sheltered location at the airport. The antenna and coupler for the receiver were located externally, up to 150 feet from the receiver. Connections between the computer and the indicator were made via a direct hard-wire pair of wires or via a dedicated phone line. Communication between the computer and the indicator were via standard BELL 103 modem tones. The transmitting power of the computer and the sensitivity of the indicator conformed to BELL 103 standards. Dial up phone lines were provided at the installation site for communicating with the remote site.

3.1.1 Loran Receiver

The Loran receiver is Megapulse Accufix 500 Loran receiver with 115vac inputs. The Accufix 500 included a Model 1000 antenna coupler with 150 feet of cable which accommodates a standard 3 meter whip antenna. The receiver includes a serial polling port interfacing to the computer. The baud rate was set at 9600.

3.1.2 Loran Computer

The Loran computer is a Zenith Z-150 microcomputer compatible with the MS-DOS operating system; it has one RS-232 serial port to communicate with the Accufix, one BELL 212A compatible 1200 baud modem, a 10mb hard drive for data storage and one 5-1/4 floppy disk drive. The operating temperature range is 60 to 90 degree F; humidity range is 8 to 80% non-condensing.

3.1.3 Indicator Unit (Annunciator)

The indicator is a 6-inch cube housing the decoder/driver circuit board and a small power supply. On its front side, it has large red and green lights mounted, as well as a buzzer with volume control and a acknowledge button. The lights and a Loran label are clearly visible from 20 feet.

3.1.3.1 Indicator Encoder

The indicator encoder is a custom made circuit housed in the Zenith. It consists of a Universal Asynchronous Receiver/Transmitter (UART) to convert the red/green status information from the computer to an encoded serial bit stream with parity. The bit stream is then encoded into tone pairs and fed into a 600 Ohm transformer to interface with the dedicated communications link.

3.1.3.2 Indicator Decoder/Driver

The indicator decoder/driver consists of a 600 Ohm transformer driving a tone decoder to recover the serial bit stream. The bit stream is fed into a UART to check for valid start/stop data bits and proper parity. Next the data byte as recovered by the UART will be checked for valid bit patterns. If good data has been received, the status is fed to the lamp driver and the 10-second timer is reset. If valid data has not been received in the proper time period, the failsafe timer will disable the green lamp drivers and light the red lamp to signify system failure.

3.1.4 Design Philosophy

The equipment is designed to minimize the probability of the green lamp being on and to maximize the probability of the red lamp being on when Loran signals are not within tolerance or the equipment is not functioning properly.

Specifically, the green lamp will be lit only in the indicator unit receives a "go" signal at least once every 10 seconds. The red lamp will be lit if a different predetermined signal is

received by the indicator, or if no proper signal has been received for the last 10 seconds.

Any of the following equipment failures will cause the red lamp to light:

1. Open circuit in lines between computer and indicator.

2. Grounding of lines between computer and indicator.

3. Short circuit in lines between computer and indicator.

4. Loss of power to the computer.

5. Any bit error to cause "go" message to go unrecognized.

3.1.5 Software Architecture

The EIP software was written in the "C" language and delivered in 5 phases, matching the delivery of the equipment (see Section 2.3.1). Figure 3-1 shows the EIP System Architecture.

Phase 1 of EIP software construction met the requirements to control the indicator box. The computer communicated with the receiver data, made comparisons with a parameter file, and sent output to the red and green indicators. Phase 2 added remote monitoring and command capability to allow computer interaction with the Loran system. Phase 3 created log files to collect and archive data. Phase 4 created average files, collected as 10-minute averages during green monitor status. The final phase created an historical record of alarm events with snapshot files, made up of 10 1-minute averages and 2 continuous minutes of log data preceding alarm (red light) conditions. Data held continuously in RAM is written to the snapshot file only under red light conditions. (All 3 file types are linked into the downloading phase for remote accessibility.)

3.1.6 Error Budget

The TD error budget is created from the expected differences in the measurements of the airborne and the monitor receivers. The budget is activated as an inner circle to the alarm circle. General error sources includes TD timing errors from the transmitter, TD measurement errors in the receivers, propagation model error, propagation path calibration error, and seasonal error. The following 3 errors are those included in the error budget:

1. Transmitter timing error is 0.1 microseconds.

2. Receiver measurement error is 0.2 microseconds.

3. Receivers (with waivers) have an assumed error of 0.1 microseconds. All approved receivers use the salt water propagation model.

These errors are combined in a root-sum-squared relationship. It is assumed that the values of the variables from the 2 receivers are normally distributed and independent. The resulting error budget is 0.245 microseconds (rounded up to 0.25 for implementation).

The measured TD values are read each second from the monitor receiver. The error budget is added to and subtracted from the measured value. The four readings, 2 TDs plus or minus the error budget, are formed into 4 vectors. The largest vector must be less than the radius of the alarm circle or the green light is turned off. The remaining errors are compensated for in the forecast. The expected TD values at a point are considered to be comprised of the seawater model value plus TD corrections.

TD calibration error is the difference in measured TD values when the airborne and monitor receivers are not receiving signals along the same path. The propagation bias is measured at the airport to which the airborne receiver is flying, and are distributed to the users periodically, included in the corrections.

Seasonal error is related to the frequency of the propagation corrections. In the Vermont seasonal data, the peak-to-peak variations over a period of a year were 0.5 to 0.7 microseconds. If no corrections were given, the seasonal error is one-half of the peak-to-peak value. With corrections made every 7 days, the error is less than 0.02 microseconds. When the corrections are added to the seawater model values, the resulting TDs closely represent the actual values at the airport.

In summary, the major contribution to the error budget for the EIP is the TD transmitter timing and measurement error and propagational model error. The remaining errors are corrected with the forecast.

3.2 System Operation

3.2.1 Approach Chart Development

This section assembles basic information currently governing approach chart development, in order to make available pertinent procedures and processes.

Civil instrument approach procedures are developed by the FAA after careful analysis of obstructions, terrain features, and navigational facilities. Narrative type procedures authorized by

the FAA are published in the Federal Register as Rule-Making action under Federal Aviation Regulation (FAR), Part 97. The controlled air space required to encompass the instrument approach procedure authorized by the FAA is published in the Federal Register as Rule-Making action under FAR, Part 71.

The most common originators of requests for instrument approach service are: (1) certified air carriers, air taxis, or commercial operators, (2) corporate pilots, (3) NASAO and local commissions and authorities, (3) private individuals concerned with the aeronautical development of the community, (4) FAA field facilities, (5) airport authorities, and (6) airport owners.

Flight Inspection and Procedures Branch/Staff of FAA Region Headquarters is the designated and focal point for the receipt and processing of civil instrument approach procedure requests. Supporting data includes the following:

1. Eligibility. A reasonable need must be established to warrant federal expenditures.

2. Airport Owner Concurrence. The owner of the airport be advised of a proposed instrument approach procedure.

3. Airport Data Requirements. A current Obstruction Chart or an approved Airport Layout Plan.

4. Loran Requirements. All geodetic positions including the Airpoint Reference Point should be determined in accordance with NAD27. Loran NPAs also require airport and runway elevations and height of obstacles in the approach and missed approach areas.

5. Off-Airport Obstruction Data. Non-FAA contributing elements should contact the FAA Regional Flight Inspection Branch.

6. Altimeter Setting Source/Weather Observation. Current operational status of the current and planned altimeter setting source and weather observation facilities is solicited.

7. Airport Lighting Facilities. Current and planned status of lighting facilities including air-to-ground radio control, alternate control, hours of operation, approach lighting, runway edge lightings, and/or visual lighting aids.

8. Commercial Telephone Availability. 24-hour availability of commercial telephone is required.

The Flight Inspection and Procedures Branch processes the following information:

1. Change of airport from VFR to IFR.

2. Assurance of AT control and communications.

3. Assurance of weather reporting facilities.

4. Review of navigational facilities.

5. Evaluation of obstacle identification, removal, marking, and lighting.

6. Environmental assessment.

7. Forwarding package to the Flight Inspection Field Office.

3.2.2 Flight Inspection

Prior to the commissioning of a Loran NPA, a flight inspection of the approach was conducted by the Aviation Standards National Field Office (AVN) to determine the suitability of the procedure. Section 209 has been added to the U.S. Standard Flight Inspection Manual describing procedures for Loran NPAs.

Significant flight inspection difficulties were uncovered during the flight inspection of the NPAs, some of which necessitated modifying the flight inspection procedures. They include the following:

1. The importance of proper aircraft bonding to eliminate static charge build-up was re-enforced. Proper bonding is a necessity when operating in the Loran frequency range. Aircraft that have never experienced static charge build-up in the higher frequency ranges may experience difficulties in the Loran band.

2. Accurate, airborne Envelope-to-Cycle Discrepancy (ECD) measurements are very difficult to make without special receiving equipment.

3. Accurate Loran receiver SNR measurements are difficult to make without special calibration equipment and calibration procedures.

These special Loran RNAV NPAs were approved during the EIP:

1. RWY 10R, Portland International Airport, Portland, OR, 12/18/85 (commission date).

2. RWY 31, Salem/McNary Field, Salem, OR, 12/17/85.

3. RWY 11, Laurence G. Hanscom Field Airport, Bedford, MA, 9/25/85.

4. RWY 15, Burlington International Airport, Burlington, VT, 9/25/85.

5. RWY 7, Orlando Executive, Orlando, FL, 3/26/86.

6. RWY 18R, Lakefront Airport, New Orleans, LA, 10/2/86.

7. RWY 32, Mansfield/Lahm Municipal Airport, Mansfield, OH, 3/27/86.

8. RWY 9R, Ohio State University Airport, Columbus, OH, 3/27/86.

9. Copter 087, PHI Heliport and Chevron Heliport, Venice, LA, 10/9/87. [Because Venice is a stand-alone NPA, more frequent periodic inspections are conducted.]

10. RWY 35, Kalamazoo County, Kalamazoo, MI, 11/24/87.

11. Copter 234, Steel Pier Helipad, Atlantic City, NJ, 12/10/87.

12. RWY 19, Norwich/Lt.Warren Eaton, Norwich, NY, 12/11/87.

13. RWY 16L, Manassas Muni/Harry P. Davis Field, VA, 1/27/88.

14. RWY 06, Mercer County, Trenton, NJ, 7/27/88.

3.2.3 Data Retrieval and Archiving

The computer has the capability of storing raw Loran data from the receiver for subsequent analysis and archiving. The data includes the GRI, 2 TDs, 3 SNR values, and 3 status byte sets. Initially, the TD and SNR values were averaged in 10-minute blocks, and recorded into daily files for modem transfer. Later, the last 2 minutes of raw data and the last 10 one-minute averages are kept available for recording in special snapshot files when indicator status changes from green to red. Daily files log the date and time when there could be any changes in the indicator status or any changes in the reason for red alarm status. Log entries include reasons for any failure, the latest receiver polled response, and the hourly poll. The computer was set up to store up to 14 days of log and average files.

Users with passwords may access the receiver via computer phone modem to issue any of the following commands:

1. Perform a complete reacquisition.
2. Drop a particular station.
3. Acquire a particular station.
4. Enable cycle selection.

The computer can also display certain processes, including:

1. Red/green status and poll responses.
2. Tolerance limits.
3. Changes in tolerance limits.

To keep historical records, the computer can download average and log files using the Xmodem protocol from remote facilities. When the user contacts the remote facility is connected, he may choose any of the following menu options:

1. Download a file.
2. Check current receiver status.
3. Issue commands to the receiver.
4. Access the remote monitor computer's operating system.
5. Change monitor's control parameters.
6. Upload software changes.

The process for retrieving log files and 4-hour average files is a standard routine in the EIP. Data is processed and stored at the 10 Loran monitors on the computer. Two weeks of data can be stored on site. After 2 weeks, new files are created and stored, and old data files are overwritten. Data are collected everyday for the 10 facilities with Loran monitors. Two types of files are collected and processed at the National Field Office for Loran Data Support (NFOLDS). These are log and 4-hour average files. Log files are collected on Monday, Wednesday, and Friday; 4-hour average files are collected on Tuesday, Wednesday, and Friday.

Data are collected with a PC using a modem. The operator calls the monitor on a Federal Telephone Service (FTS) line. After gaining access, the user enters the password and the screen displays the main menu. The main menu lists 6 choices: status, download, receiver, controller, maintenance, and exit (see Appendix B).

To collect data, the user selects the download menu. A submenu appears which allows the user to decide whether to download log, 4-hour average, or snapshot files (see Appendix B). The snapshot file is a detailed historical record of red light event, collected only to examine a specific alarm history.

Two weeks of data from the chosen file scrolls on the

screen. The user returns dates he wishes to download. Once data is selected, the submenu indicates file length and asks the user if he wishes to proceed. If no, he is returned to the submenu. If yes, the user is instructed to receive the data. After the file is downloaded, the computer returns to the submenu and asks the user to choose another file or return to the main menu.

After collecting the desired data on the hard drive, the computer copies the files on diskettes. Each monitor site contains 2 diskettes, one for log files and the other for 4-hour average files. An index record of each diskette is maintained in the facilities notebook.

3.2.4 Forecasting Algorithms

The FAA has adopted a policy of providing TD corrections, to account for seasonal variations, for each Loran RNAV approach. This reduces the MOPS error allowance for seasonal variation from 0.75 microseconds, when no updates are given, to 0.15 microseconds, when frequent updates are supplied. A lower system error increases the availability of a Loran NPA. Two forecasting algorithms were developed and evaluated during the EIP. The 7-day forecast, the EIP's original method of prediction, supplied weekly updates. EIP was later upgraded to a 56-day forecast supplying upgrades every 8 weeks. Both methods greatly reduced seasonal errors and allowed proficient NPA operation.

Giving the user community corrections on a weekly basis (7-day forecast) meant reduction to near zero of the error budget for seasonal variations. This allowed the EIP to maintain the radius of the alarm circle at 0.3 nautical miles, matching the FAA's NPA specifications. Week-to-week variations were approximated with a linear functional relationship between collected TD values and time. Linear regression was used to relate a response variable to a descriptive variable, through a set linear equations of the form:

$$yi = B0 + B1*xi$$

where

- xi = the TD hourly average
- B0 = the first hourly TD average minus the aggregate average of the hourly TD averages
- B1 = the last hourly average minus the first hourly average divided by the total number of values used.

The algorithm used 168 hourly averages, fitting a trend line to them using least squares criteria, to determination B0 and B1. This made the sum of the squares of the discrepancies between the trend line and hourly averages as small as possible.

With B0 and B1 the trend line is extrapolated into the following week. Inserting the desired hour into the linear equation produces the needed forecast. An estimate of the accuracy of the fit of the trend line was also computed. The calculation is a standard error of estimate. The calculation is the square root of the sum of the unexplained deviation of the actual data points from the trend line. Each of these estimates is on the order of 10 nanoseconds.

The progression of the forecast to an 8-week period accommodated the FAA's approach plate update schedule. Since the seasonal behavior of Loran was sinusoidal, the Fourier method was used to develop a least squares approximation of the trend line. The following is a description of the calculation method.

The first step in the process is to subtract the linear tendency y(x) found in the given data. This guarantees that the function is smooth and differentiable. The new function is:

$$w(x) = y(x) - (y(0) + ((y(n) - y(0))/n)*x)$$

where $x = \{0,1,2...,n\}$
n = number of data points

the function w(x) is used to calculate the sin terms a_j used to build the trend line.

$$a_j = (2/n) * \left(\sum_{i=1}^{n-2} w(i+1) * \sin((j*\pi*i)/n) \right)$$

where $j = \{0,1,2..m\}$
$\pi = 3.14159$
m = number of terms calculated

The maximum number of terms that can be calculated is n-2. Since many of these terms add error to the approximation, m is limited to the point where a_j adds only error to the approximation. This point is found when the graph of the function $1/(j^3)$ and $1/(a_j^3)$ do not agree. The computer compares the slopes of each line. If they vary by a set limit, calculation of a_j is stopped. With these terms the trend line is constructed:

$$TD(t) = y(0) + ((y(n) - y(0))/n)*t + \left(\sum_{j=1}^{m} a_j*\sin((j*\pi*t)/n) \right)$$

where t = predicted times value

Using a trend line generally based on 26 weeks of input values, the 56-day TD forecast algorithm calculates TD values for the Monday following the fourth week of the forecast period; that

day is chosen as the midpoint of the 8-week forecast to minimize the error throughout the entire period. The set of graphs displaying the monitor 4-hour TD averages (see Appendix E) also give the forecast values given to users of the system.

3.2.5 Security

EIP uses a menu driven software system to dial receivers to check status and download data files. A security system built into the automated software limits access to authorized personnel. The EIP staff monitors remote receivers twice a day for a general inspection of the status.

The Loran system operates on the IBM PC/XT and compatibles using MS DOS 2.0. The software, called LASER (Loran Accuracy, Status and Error Recorder), gives users access to the monitors.

Once the remote site has been accessed, a message warns the user that the call has reached an FAA facility and a password is required (see Appendix B). This first level of security allows the user entry to the LORAN Monitor. The password is made up of 13 characters. The combinations for a 13-letter password--with upper and lower case, the numerical keys, and shift equivalents--is very large. A total of 96 keys gives $(96)^{13}$ combinations. The NFOLDS system is designed with macros, which alleviate repetitive keyboard entries.

The main (LASER) menu offers 6 options: Status, Download, Controller, Receiver, Maintenance, and Exit. The Status, Download, and Exit menus are at the first security level; they allow the user to check monitor conditions, collect (download) any or all data of interest, and leave (hang up modem) the system. Higher levels of security control the Controller, Receiver, and Maintenance menus. These menus are all equally vital, but each is protected by an individual password. These 13-character passwords use more complicated selection of upper and lower case as well as non-alphanumeric characters, making accidental access virtually impossible.

The Controller menu gives NFOLDS staff authority to change threshold parameters: Signal-to-Noise Ratio (SNR), TDs, GRIs, Gradients, Receiver Time Constants, Crossing Angles, Monitor Radius for distance errors.

The Receiver menu allows the operator to manually reacquire the Loran signal following a red status condition. The options are: power the receiver from the beginning, allow the receiver to select its proper tracking cycle, allow the receiver to only check for proper tracking point, or to disable any of the receiver cycling functions. The software automatically attempts to restore proper receiver operation: if a transmitter station is

lost, the computer immediately turns on a red lamp and commands reacquisition before deciding that the receiver is faulty.

The Maintenance menu allows the user to upload (send) files, such as new versions of DOS, to the Loran monitor. Correcting internal clocks for daylight savings time and date changing are done here. This protected menu requires a good understanding of DOS procedures to avoid system file damage.

3.2.6 Pilot Feedback

One of the earliest EIP components was a feedback method for pilots to comment on the adequacy of a Loran NPA. Response forms registered pilots' remarks on 311 NPAs. The forms, first issued in 1985, were designed to spur pilot involvement in the program, provide a channel for suggested improvements, and check the accuracy of the correction values. In all, 49 pilots returned 287 response forms to NFOLDS.

The EIP has not been free of problems. New England users at Hanscom and Burlington submitted only 6 pilot reports before the airlines went out of business. Because of poor Loran signal geometry, Lakefront replaced Beaumont/Port Arthur. EIP received no pilot reports from the Texas airport. Lakefront sent in 10 reports in 1986. Portland, one of the original 4 airports in the EIP, submitted 11 reports representing 10 approaches; on one occasion the pilot's receiver and the EIP monitor were in alarm status, thus the pilot could not make the Loran approach. Columbus sent in 15 reports in 1986.

In 1986, with only 42 pilot reports in hand, the Loran Working Group determined that the EIP produced far fewer sample operations than expected. This resulted in less than adequate experience to proceed directly with a full design for the NAS. At least 2 Loran traits, which might limit system operation, needed further study with pilot reports. First, the human aspects associated with earth-referenced navigation could create an unacceptable cockpit work load. How can pilots and controllers effectively use systems that use latitude and longitude as a primary language at the man/machine interface? Second, the probability of a receiver acquiring or tracking the wrong cycle of the Loran signal was too high and the results, if undetected, unsafe. What methods work best to prevent (or at least detect) incorrect cycle acquisition of the Loran signal? Is limiting NPAs to areas of good Loran SNR and GDOP adequate? Does such a solution severely limit the areas for approved NPAs? Can operational cross-checks between Loran and other NAS navigation systems effectively warn the pilot if the Loran receiver is tracking an incorrect cycle? Answers to these questions needed more response from pilots.

The Loran Working Group met with the user community to request more pilot reports. II Morrow, Inc. enlisted 54 EIP volunteers, owners of their navigation receiver, Apollo II 612A. The number of reports jumped to 41 in 1987 and tripled (123) in 1988. In 1989, there are 81 reports on file. (See Figure 3-2.)

There were 11 alarms during approaches and one during an en route section. One flight recorded 4 alarms before starting an approach, 3 of 10 seconds duration and one of 5 seconds. Though 7 other alarms resulted in missed approaches, the status of the airborne receiver and the monitor receiver were always in agreement. There were no incorrect cycle acquisitions reported. It appears that areas of good Loran signal-to-noise and good geometry are an adequate safeguard from incorrect cycle acquisition.

Two pilots complained about cockpit workload. The first objected to the effort required to insert an area calibration, i.e., inserting latitude and longitude and TD values. Since the TSO requires that pilots with approved receivers insert a correction value of 3 digits for each baseline, this work load criticism is not relevant to owners of approved receivers.

In the second case, as one pilot was deploring cockpit workload, a second pilot made the identical approach and recommended that the system expand. Scrutiny of workload comments show their origin to be predicated on traffic flow rather than Loran traits.

Pilot reports recounted all types of weather operations: snow, rain, electrical discharge, and gusting winds. They confirmed that Loran is indeed an all weather navigation aid.

Over 70% of the reports (199) were from pilots using receivers with the capability for correction insertion required by the TSO. The others used area calibration. Six airports are active users of correction values: Orlando Executive (70 approaches), Kalamazoo (59), Ohio State (34), Lt. Warren Eaton Field (13), Portland International (13) and McNary (10); (see Figure 3-3.)

To sum up, the 287 pilot reports showed 311 attempted NPAs; 304 approaches were completed using Loran for guidance; 49 pilots used the navigation aid for NPAs. In all 7 approaches where the pilot's equipment went into alarm status and he executed a missed approach, the monitor system confirmed the alarms. More than two thirds of the landing sites actively sending in pilot report forms inserted the published corrections. Every report that commented on the comparison of guidance success declared improved attainment of centerline with use of the corrections.

3.3 Program Enhancement

Although it was originally planned to operate the EIP for a period of about one year before the system would be in operation, that time frame increased and the only practical means of accommodating more users was to expand the EIP. The number of monitors purchased for the EIP was fixed at 10 so that monitors had to be moved from inactive sites to central locations which served multiple landing sites.

3.3.1 Non-Tower Locations Of Loran Monitors

Loran monitors are located at the following ATCTs: Portland, OR; New Orleans, LA; Orlando, FL; Columbus, OH; Burlington, VT. Loran monitors are also located at the following flight service stations and automated flight service stations (FSS & AFSS): South Bend, IN (removed August, 1989); Lansing, MI (not installed); Utica, NY; Millville, NJ; Leesburg, VA. It should also be noted that NFOLDS at TSC in Cambridge, MA has its own Loran monitor, used for data collection and software development. The 3 main levels of location for Loran monitors are as follows:

1. ATCTs: Alarms are processed at a real time rate of less than 10 seconds at the clearance delivery point.

2. AFSS and FSS: Alarms are processed in quasi real time. FSS operators must call the clearance delivery point at the ARTCC.

3. VORTAC Sites: Sites of installation of the 196 newly purchased Loran monitors for the CONUS. NOTAMs are provided by AT facilities, on request of the AFS technician, for out-of-tolerance conditions.

3.3.2 Venice

The FAA required that NFOLDS make measurements at Venice to assure aviation safety. The site of the Venice Loran antenna was a microwave communications station located approximately 300 feet from the landing site. A spectrum analysis of the site showed no adverse effects from the microwave signals on the Loran frequencies. With this established and the parameters file set, the unit started creating 10 minute average files. The mean TD for Lakefront and Venice, for the Whiskey and Xray baselines, are plotted against time (see Appendix F). Time 1 represents midnight April 29, 1987 and time 500 represents May 2, 1987 at 11:10am. The figures show that the TDs track each other. The only major anomaly was due to work being performed near Lakefront's monitor antenna. The analysis of these plots showed that

Lakefront variations match Venice variations with errors in tens of nanoseconds. This demonstrates that Lakefront could adequately predict the Loran signals at Venice with an adjustment in the Lakefront monitor error budget.

The error budget for the airports in EIP is 250 nanoseconds. The natural phenomena TD calibration error term is zero when the airport and monitor are collocated. The FAA set the calibration error for Venice using Lakefront's monitor at 30 nanoseconds, or twice the standard deviation of the TDs between the two sites. The total error budget remains at 250 nanoseconds, since the 30 nanoseconds is root sum squared with the other error terms.

With Lakefront monitor established as a viable means for monitoring Venice's Loran approach status, a procedure had to be developed to relay the information to the user. An annunciator installed in the Houston ARTCC, the clearance delivery point, with a dedicated phone line linking it to the Lakefront monitor, enabled Houston to give Venice's Loran signal status on request.

3.3.3 Amchitka

On August 17, 1988, the first Alaskan revenue-producing Loran NPA was flown, using Loran RNAV 1 to Runway 25 (Baker runway from World War II) on Amchitka Island. This flight was witnessed by an FAA/TSC team, including TSC Director Lou Roberts.

Amchitka's approach is unique among all others in the EIP for these reasons:

1. There is no associated FAA monitor.

2. There are no seasonal corrections.

3. There is a technique for verifying that the receiver has acquired the correct cycle.

4. On the approach path, a 75 mHz fan beacon radiates a vertical conical pattern.

The marker is placed 4.7 miles from the end of the runway. A typical approach is to travel over the beacon at 1500 feet, continue on, and do a routine procedure. Pilots insert the runway end coordinates as the Amchitka way point. The distance to the runway end should agree with the 4.7 miles from the marker, verifying correct cycle acquisition. The Missed Approach Point (MAP) also is the end of the runway. Latitudes and longitudes are available for Loran input on the approach plates.

At the marker site, a VHF transceiver can be interrogated with 5 clicks of the microphone switch at its operating frequen-

cy. This procedure causes the beacon modulation tone to be transmitted. Pilots can call from up to 100 miles to check the beacon's operation; this radio accessibility makes maintenance and troubleshooting easier, with less down time. The beacon is operated by a battery, recharged by a wind generator.

Earlier FAA flight inspection tests were conducted at altitudes of 1500 and 2500 feet. The test at 1500 feet measured a circular pattern, with a diameter of 1200-1400 feet. The test at 2500 feet measured a wider pattern, 3000-3500 feet in diameter.

Figure 3-1. System Software Architecture.

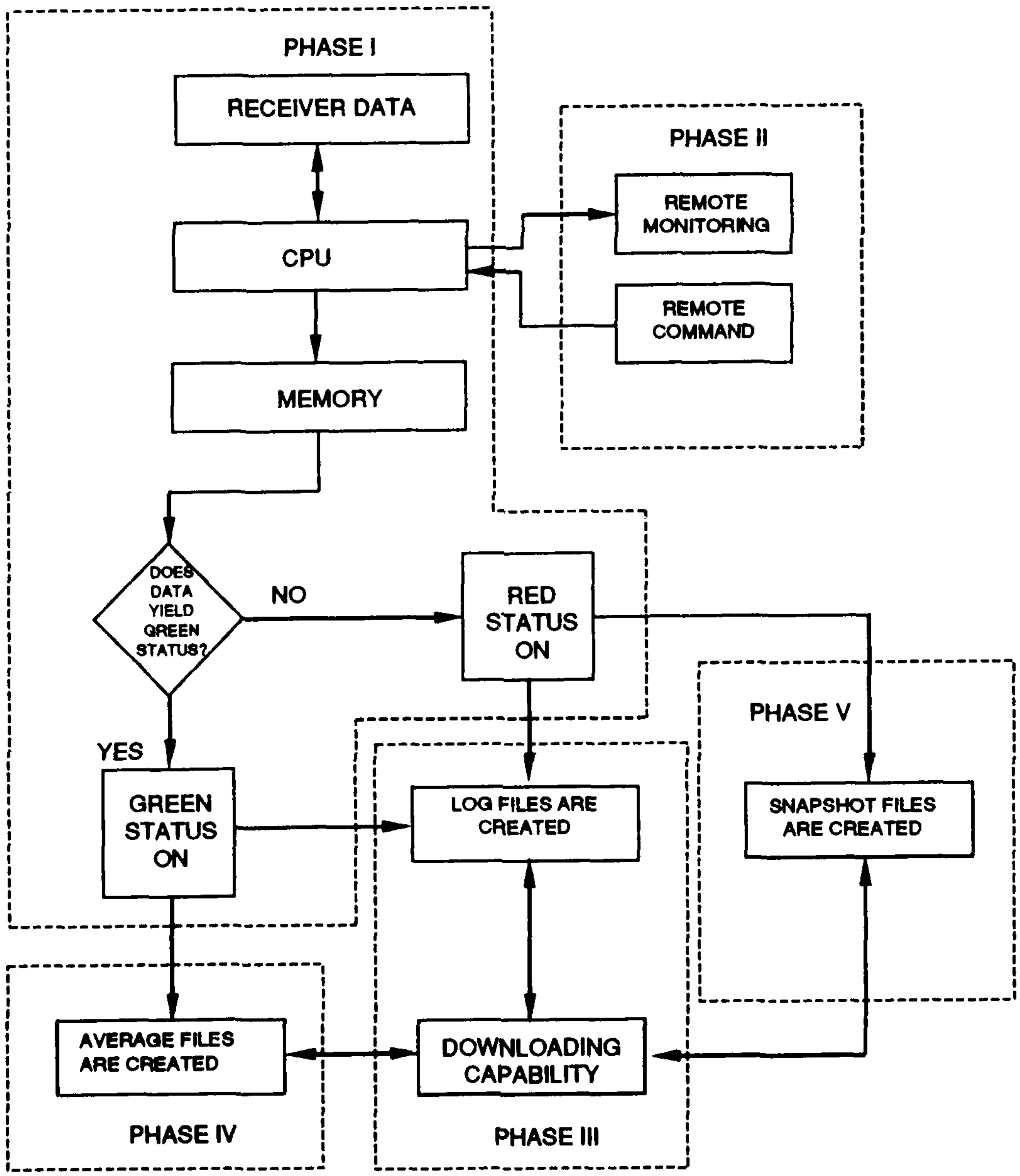


Figure 3-2. Summary of Pilot Reports.

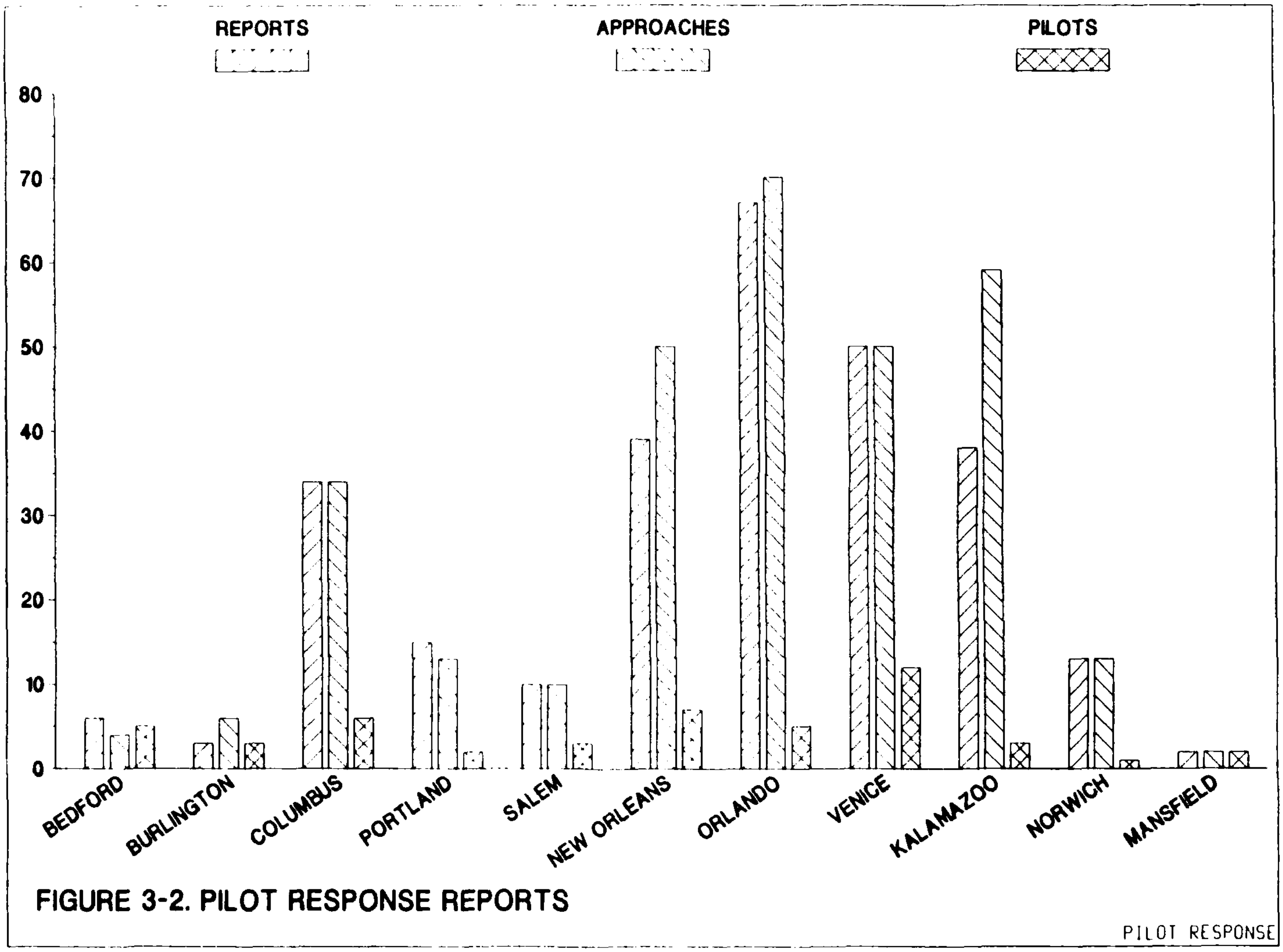


FIGURE 3-2. PILOT RESPONSE REPORTS

Figure 3-3. Pilot Response Report Frequency.

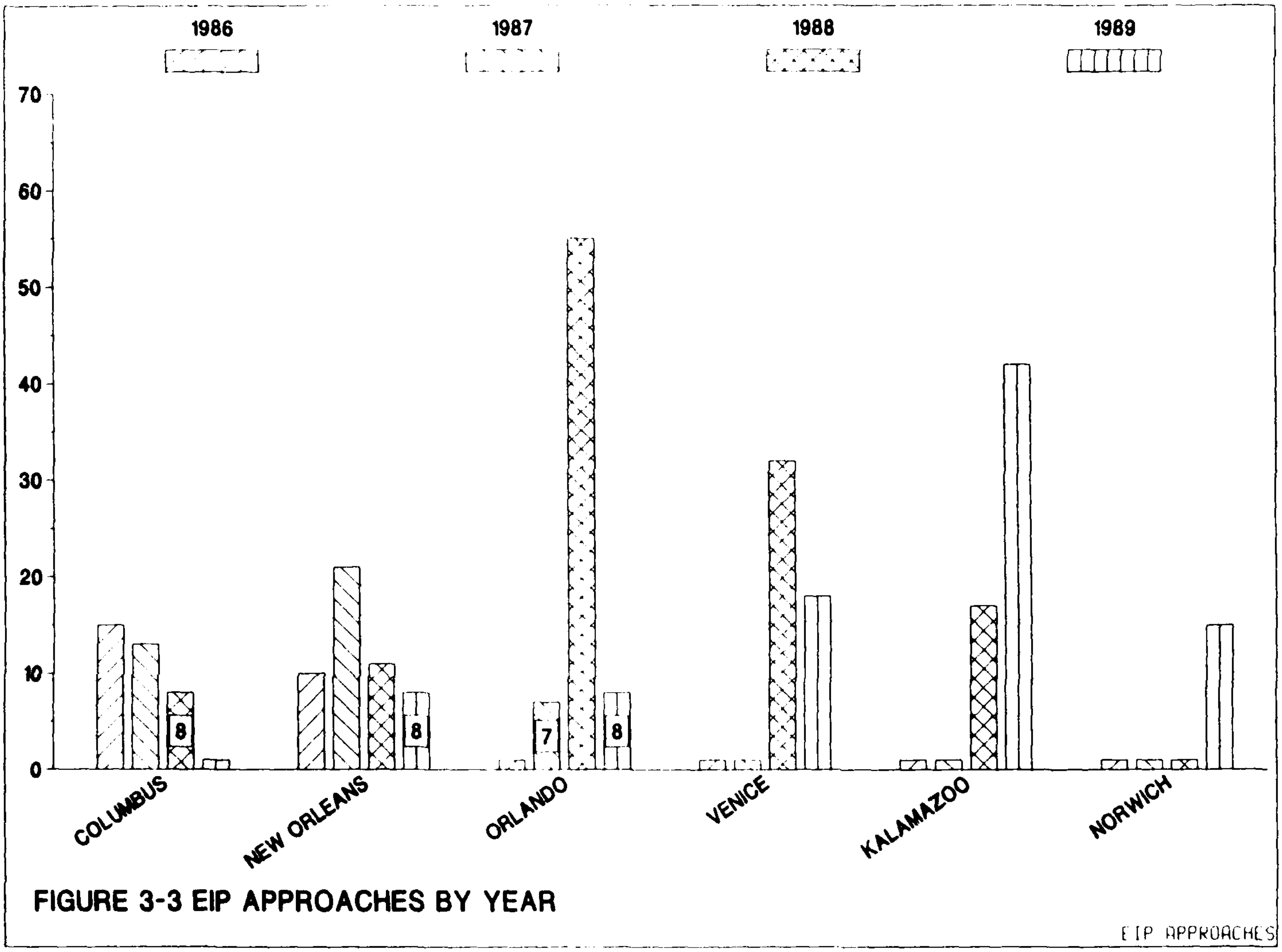


FIGURE 3-3 EIP APPROACHES BY YEAR

4.0 DATA ANALYSIS

The EIP monitors serve a dual function: they provide indicators of Loran signal integrity and serve as a medium for collecting a large amount of data on signal quality and accuracy, as well as the operational characterisics of the entire system. Section 4 presents a detailed analysis of the Loran signal parameters and the distribution of monitor alarms that were measured during the EIP.

4.1 TD and SNR Analysis

The FAA Loran monitor was conceived as an interim NPA aid to bring Loran into the NAS. While supporting NPAs, the monitors gave the FAA the added opportunity to develop a data base of Loran information from several locations nationwide. This data base contributed greatly to the studies described in this report and helped shape Loran policies. Some of this data base is presented as line plots: SNR averages and minimum values (Appendix D) and TD averages paired with TD forecasts (Appendix E). Brief explanations of these sets of plots follow, and some conclusions are drawn from the data.

SNR plots are 4-hour averages plotted against time. Each site includes a plot for the 3 monitored transmitters. Two sets of minimum values (Orlando and Lakefront) were included to show a worst case scenario for minimum SNRs. Every value recorded corresponds to the minimum value in the 4-hour period. SNRs are estimated by the monitor's receiver using 20log(A/sigma) where "log" is base 10. "A" is the amplitude of the Loran signal envelope at the tracking point. Instantaneous readings of noise as detected after passing through the receiver front end are assumed to have a Gaussian distribution with mean zero and standard deviation "sigma".

The SNR average plots are grouped to show relationships between monitors with identical triads. The first two sites displayed (Hanscom and Burlington) show the effects of locating two monitors at different locations in New England. As expected, the closer the monitor is to the transmitter the greater stability of the SNR recorded. This can be seen by looking at the monitor's 2 Nantucket plots. Hanscom, which is closer to Nantucket, shows greater SNR stability. This effect also is demonstrated with the Ohio monitor sites: Mansfield, closer to the Dana and Seneca transmitters, exhibits greater stability than Ohio State. Analysis of the SNR averages shows how stability affects the monitor's noise alarm occurrences (Portland and McNary). Fallon and Middletown monitors, responsible for the

majority of noise errors recorded at these two sites (see Section 4.2.5), are less stable than the SNRs recorded from George.

Minimum SNR values as mentioned above are displayed for the Lakefront and Orlando monitors. It can be assumed from these plots that the environment is noisiest during the summer. Comparing the stability of the average plots and the spikes on the minima plots, it can be assumed that the noise is impulsive rather than steady state.

The TD plots are also 4-hour averages plotted against time. For each site, 2 TDs are displayed as well as the TD forecast supplied to users. The 7-day forecasts are the short horizontal lines at the beginning of the data collection period. Longer horizontal lines are the 56-day forecasts. These methods of forecast are described in Section 3.2.4. TDs were collected at a resolution of one nanosecond after smoothing with the selected time constant. The frequency of data collected was approximately once per second. The data was filtered during alarm conditions to limit adverse effects on the forecasts. An exception to this occurred when the system software was modified to establish a 7 out of 10 out-of-tolerance voting scheme before alarm. The software allowed the first 6 out-of-tolerance events to be recorded before the data was filtered. These events are seen as spikes throughout the TD plots and should be ignored.

Data analysis begins with sites without extreme temperature variation because they tend to be very stable in terms of TD variation and forecast. Lakefront, the best example, has a very small seasonal temperature variation and saltwater paths to each of its transmitters; its peak-to-peak TD variation was only 0.05 microseconds. Pilots who used this monitor's forecast needed only one set values for the entire year. The 1.5 microsecond jump of Lakefront's TDs during 1986 was due to a relocation of the monitor to a new tower. Orlando shows similar characteristics to Lakefront, with a minimal TD variation for both baselines. Portland and McNary, the Oregon monitors, can also be considered fair weather sites. Both have TD variations of no greater than 0.2 microseconds.

The next group of monitor plots show a moderate variation in TDs. Millville, for example, has TD variations of approximately 0.3 microseconds. The plot of Millville's Yankee baseline has an inverted TD seasonal variation. This variation is due to the location of the SAM and its time of emission adjustments. Other plots with moderate TD variations (i.e., in the 0.3 to 0.4 range) include Hanscom and Manassas. Differences between the forecast values and the TD variations for all the above sites are well below 0.1 microsecond. This small error does not significantly degrade the accuracy of an NPA using the forecasted values.

The last group of plots show extreme TD variations: peak-to-

peak variations which range from 0.6 to 1.2 microseconds. These variations are due to a combination of seasonal temperature variation, location and SAM location. Sites like South Bend (worst case) had variations of up to 0.9 microseconds in just a couple of weeks. This was not a concern with the weekly forecast but did come into play when the switch to a 56-day forecast was made. Such wide variations did not cause monitor alarm because of their good Geometric Dilution of Precision (GDOP), but could limit sites with larger GDOP. Other plots with large variations are Utica, Burlington, Ohio State, and Mansfield.

4.2 Alarms Analysis

The EIP hardware is designed to alarm when the signal characteristics exceed predetermined limits. The limits are conservative. As operational experience was acquired, the alarm limits were varied and data collected to assess impacts of the changes on alarm frequency and work load. Experience with the EIP unit guided the design of the operational monitor.

The EIP monitor unit combines a receiver, computer and a indicator unit. The receiver sends to the computer a two digit message. The message tells the computer if it is tracking the chain selected for the location. In addition it tells the computer if a transmitter is blinking, or if the receiver has lost a signal. The computer turns on the green lamp when the signal is being tracked and is within limits.

The monitor computer determines whether Loran system margins are suitable for an NPA within the boundaries of AC 90-45A and if the environment matches or exceeds the minimums set in TSO-c60b. The indicator unit contains a green and red lamp (2 of each for redundancy) and an annunciator. The green lamp is lit when the Loran signals are known to meet the quality criteria. The red lamp is lit if the Loran signals are out of tolerance or if there is an equipment malfunction. The annunciator will sound each time the red lamp is lit; its volume can be turned down or off.

The equipment design minimizes the probability of the green lamp being on and maximizes the probability of the red lamp being on when the Loran signals are not within tolerance or the equipment is not functioning properly. Specifically, the green lamp is lit only if the indicator unit receives a predetermined signal at least once every 10 seconds. The red lamp is lit if a second predetermined signal is received by the indicator, or if no proper signal has been received in 10 seconds.

Any of the following equipment failures causes the red lamp to blink and the green lamp to cancel: open circuit, short circuit, grounding in any lines between computer and indicator, or loss of power to the computer but not to the annunciator.

4.2.1 Green Lamp Criteria

The computer requests Loran data from the receiver at a nominal rate of once per second. Green lamp criteria are as follows:

1. Status bits sent from the receiver are normal, indicating that the receiver is tracking the triad, and no transmitter station is blinking the signal.

2. The frequency of the oscillator in the receiver is within +\- 700 nanoseconds of the chain group repetition interval.

3. TDs are within tolerance.

4. SNRs are within tolerance.

4.2.2 Multiple Alarms

When there are multiple alarms, only the highest priority error will be shown in the data file. Alarm rank is as follows:

HRD: Hardware failure suspected because the receiver has not acknowledged the keyboard lock command on schedule.

PAR: The control or limit parameter file could not be read when the computer was powered up.

CHG: Changes are being made to the limits.

The transmitters also are ranked: master, first secondary, and second secondary. The rank of the master alarms are as follows:

TIM: Timeout, no report from the receiver on the master transmitter in 10 seconds.

STS: Status bits from the receiver on this master are unacceptable. The transmitter is in blink or the signal is lost. Other receiver status messages are sent to the computer to help the operator diagnose the current state of the receiver: in search, tracking too high and cycle status enabled, tracking too low and cycle status enabled, or receiver is performing front edge location.

NOI: SNR is too small or has not been available for over 10 seconds.

OSC: Oscillator in the receiver is out of tolerance +\- 700 nanoseconds, or the transmitter group repetition interval has changed. Secondaries are ranked in the same order except there is no OSC alarm.

There are 2 more error codes or alarms:

DIS: Distance from the true location as calculated from the TD deviations exceeds the preset limits.

POW: System lost power and requires parameter verification.

The real-time measurements available to the receiver on which to base the determination to turn on the green lamp are TD values, SNRs, and receiver status. If the status is satisfactory, (i.e., the receiver is in track), the computer accepts the SNR data from the receiver monitor.

SNR limits are commonly set at -6 decibels (db). Unusual atmospheric conditions or rain static can cause a non-green state. SNR limits were set as low as -10 db to determine the increase in the number of alarms. All receivers examined to date can easily acquire and track signals in this type of environment.

TD measurements are given a +\- 250 nanosecond bias and then converted to latitude and longitude (there are 4 different positions from this operation). The length of the 4 vectors are computed and compared with the confines set by AC 90-45A. If all 4 vectors are less than this limit, the green lamp remains on.

These 3 conditions--status, SNRs, and distance--are measures of signal quality or availability. The EIP collects and analyses data on each of these conditions.

The limits on the receiver oscillator offset are set in the processor at +\- 700 nanoseconds, i.e., if the measured value of the 9960 GRI is greater than 99600.7 microseconds or fewer than 99599.3 microseconds, the green status is not turned on. This function is a measure of receiver performance rather than a timing failure at the transmitter. If the offset stays within +\- 700 nanoseconds, TD accuracy requirements in the receiver will be met. The measured values of TDs are adjusted by the measured oscillator offsets.

This condition and 5 others are considered as monitor or operator overhead categories:

1. No report from the receiver for 10 seconds.
2. Hardware failure.
3. Parameter file cannot be read after return of power.
4. Changes in progress in the control or limit file.
5. Lost power.

Loss of power is recorded as a separate category; the remaining 5 are grouped in a category labeled as "other."

4.2.3 Initial Settings

The system installed at Hanscom Field in 1985 was set to alarm if the SNR was less than 0 db and if the position as indicated from the signal was less than 0.2 nautical miles. Data from the receiver was analyzed each second and the time constant was set at two seconds. This monitor was extremely sensitive to all environmental changes. In 1986, it recorded 3104 alarms. Signal quality or availability accounted for 2589 events. Loss of power accounted for 73 events. Other events numbered 442. Figure 4-1 shows bar charts of Hanscom events in 1986 and 1987.

The first setting change (1986) was to permit the computer to reset the green lamp when the alarm was deactivated. The monitor compared existing parameters with the stored parameter file, reducing the need for an operator to adjust the system. The second change introduced a voting scheme: in a 10 second period the event had to occur 7 times to be registered. The SNR was lowered to -6 db and the vector length (including offset) was put in at 0.3 nautical miles. There was an 80% reduction in events after the change at Hanscom, with only 771 events recorded in 1987. Overhead or operator-caused events amounted to 3%.

Reductions in the alarms (ranging from 86% to 25%) took place at every monitor site. Bar charts for all 8 sites are in Appendix G. The overhead rate was reduced to 10% or less.

Significant setting changes in the 1988 data were the increase in time constant (equivalent) from 2 to 10 seconds and the assistance from the local technicians to improve the source of power. In 1988 there were no power losses. The desensitized receiver greatly reduced the alarm count. Though SNR alarms were reduced by 80%, the status bit alarm numbered a disturbingly high 3011 for 5 sites. Figures for this data are in Appendix F.

4.2.4 Status Bits

Status bits indicate the state of the receiver. A status alarm is caused by an event at the transmitter: blinking signal, no signal, or the receiver is searching for the signal. With the cooperation of the USCG at the Seneca transmitter correlation between transmitter outages and receiver status alarms exceeded 95%. Several recommendations were suggested to reduce the alarm rate. The voting scheme could be changed to 60 seconds of status events before initiating an alarm. This prevents the monitor from reacting to the momentaries (events at the transmitter of less than a minute's duration).

4.2.5 Signal-to-Noise Ratio

For 6 months, November 1988 to April 1989, the parameter for the SNR signal was decreased to -10 db. This data was studied to determine the potential for alarm reduction. Figure 4-2 displays the difference between -6 db and -10 db limits for identical periods of time one year apart for Portland. Figure 4-3 shows similar conditions for Lakefront.

Portland and Lakefront show the greatest improvement in alarms numbers. Both airports' history of noise alarms (Portland had 432 in 1988, Lakefront 662) prompted the use of special installation techniques. Portland's antenna is half height and tuned filters were placed at interfering frequencies. Both techniques decreased the noise.

At Portland, changing the SNR limit reduced alarms by 14%. In 1987, there were 327 alarms; in 1988, there were 284. Lakefront reduced the number of alarms by 27% with a change of limits from -6 to -10 db. In the 6-month period starting in 1987 Lakefront registered 635 alarms; in 1988, 457 alarms were registered. Again, receivers experience no difficulty acquiring the signal at the lower limits.

4.2.6 Distance

One additional software change caused distance violations to be recorded in the snapshot file with 1200 additional seconds of data after the event. This permits a complete assessment of the extent of a distance violation. It answers the question, "How far did the signal drift from the center line?" The integrity issue which the FAA has been forced to address is the possibility of the so called "slow TD drift". The problem is that of large variation of TD due to changes in the propagation path at far distances from the USCG SAM. The positional errors which these TD variations produce would not be detectable either by the USCG or in the cockpit. The EIP monitors were designed to produce alarms whenever the position determined by the TDs was outside the proscribed limits.

The EIP software identified 51 violations as distance since the software modification was installed in January, 1989. Ten of these cases were alarms initiated for other reasons which extended into the following hour and were designated on the hour as distance by the software. At 2 sites, incorrect input value led to 16 distance alarms until the values were corrected. At Portland, an incorrect error circle caused alarming to occur for TD variations of 100 nanoseconds during the period from 3/1/89 to 4/26/89. At Utica, an incorrect forecast value also caused

alarms at the 100 nanosecond level from 4/26 to 5/11/89.

In the rest of the cases (25), the TD variations were larger (on the order of 1 microsecond) and occurred over a period of time less than 2 minutes. Since the time scale was much too small to be attributed to propagation effects, causes had to be either a timing error at the transmitter or a monitor malfunction. In all but two cases, alarms initiated by distance violation indicated a status condition (such as blink) a short time into the alarm.

4.2.7 Summary

In the last year of the EIP, there were 9 months of data from 7 monitors and 6 months from another. The monitor in South Bend was removed and scheduled for relocation to Lansing FSS. It stopped recording data on July 4, 1989 and was removed in August. The 8 monitors logged 7096 alarms (see Figure 4-4.) Transmitter operation alarms (58% or 4094), can be reduced by changes in transmitter operation or in monitor software. Noise in the area caused 27% of the alarms (1894). The operational monitor in the future will be housed in the VORTAC, sited in a low noise area.

Loss of power was not a problem; no FSS monitors had power outages. All power outages recorded in 1989 came from Orlando and were operator induced, a sharp contrast with no power losses from that location in 1988. Distance alarms accounted for 51 events, but none of these are real. The other (812) events were caused by operators. Careful operation and analysis has reduced the number of alarms from more than 9000 at one site to 7096 total from 8 sites, with no decrease in the level of safety.

4.3 Transmitter Outages

The present USCG policy is to consider any signal interruption of less than 60-second duration as a momentary and to not count it in the signal availability calculation. Typically a station's transmit performance is 99.953 percent with 19 minutes unusable, with reasons for the unusable time (e.g., power failure). The control performance is typically 99.993 percent with 3 minutes unusable, with reasons for the unusable time (e.g., control watchstander error.) Momentaries also are recorded and summarized in USCG monthly reports.

The EIP staff analyzed 6 months of status alarms from the monitors watching signal performance of the Northeast Chain. The analysis determined the duration of the events, most of which were caused by momentaries (events of less than 60-seconds). A histogram of the number of events versus duration time showed that, in most cases, transmitters and monitors recovered within

30 seconds of first detecting an out-of-tolerance event (76% of status events lasted less than 27 seconds). Events longer than 60 seconds were: scheduled by USCG; unscheduled and off-air; or identifiable by a blink status.

The next step in analyzing the events was to compare the time of the events with USCG records. EIP personnel on December 5, 1988 visited Loran station Seneca, which controls 9960/NE and 8970/GLKS chains. After reviewing the monitor data, USCG personnel agreed that the monitor events were related to transmitter outages. The time of the momentaries and the time of the monitor events were compared.

A comparison of USCG outage logs with EIP monitor data for July through December 1988 concluded that 95% of EIP status outages were matched with logged momentaries. The unmatched events were induced by EIP staff; whenever they reset the monitor receiver, it began searching for the transmitted signals.

The 3 major causes of momentaries are transmitter/coupling network switching, weather, and power (see Figure 4-5). One interesting observation about the USCG momentaries is that the EIP monitors recorded no events categorized by the USCG as "weather". This suggests that weather-designated events had a duration of less than 7 seconds, the minimum for EIP to register an event. Power-designated events occur when there is an interruption in local power. There is a 40 to 45 second delay before standby power units take over.

A momentary occurs when the primary coupling network is switched to the backup coupling network causing a delay of approximately 30 seconds. This is done automatically as a protection mechanism when an overload or low power in the transmitting system occurs. It is frequently associated with lightning storms or high humidity. The EIP data shows that these events happen in pairs. There is a USCG policy to return the switch to the primary system after an outage. The USCG informed EIP personnel that this policy has recently changed so the system will continue to run on the backup after a momentary occurrence. This policy change reduces the number of switching events by 50%.

4.3.1 Equipment Modification

The previous section shows there is a need for two courses of action at a transmitting site to substantially reduce the number of status events occurring at monitors and in airborne receivers. First, power momentaries can be eliminated by including uninterruptable power supplies at each transmitter site. This unit would supply power to a station from the time when commercial power was lost until the backup system is ready to assume the load. Another consideration is the operation of

backup power during critical flying periods when severe weather or thunder storms are forecast. This would reduce but not eliminate power momentaries.

Second, a study should be performed to analyze the benefit accrued from modifying transmitting equipment to reduce the switching momentaries. Since the switch is a form of equipment protection, the study would focus on reducing the length of an outage during a switch. Duration times of less than 7 seconds are not detected with FAA monitoring systems. The USCG might continue its policy of eliminating the return to the original coupling unit after a switch to backup has occurred, which eliminates half of these outages.

4.3.2 Policy Modification

Analyzing the data shows momentaries cause a complete loss of signal at the monitor sites. This suggests that if a momentary is detected there is no requirement for the FAA's operational monitors to go into an out-of-tolerance state which requires a physical reset of the system. This type of alarm will be detected by aviation receivers that meet the standards in TSO-c60b, "Airborne Area Navigation Equipment Using Loran C Inputs." Paragraph 2.2.1.10 states:

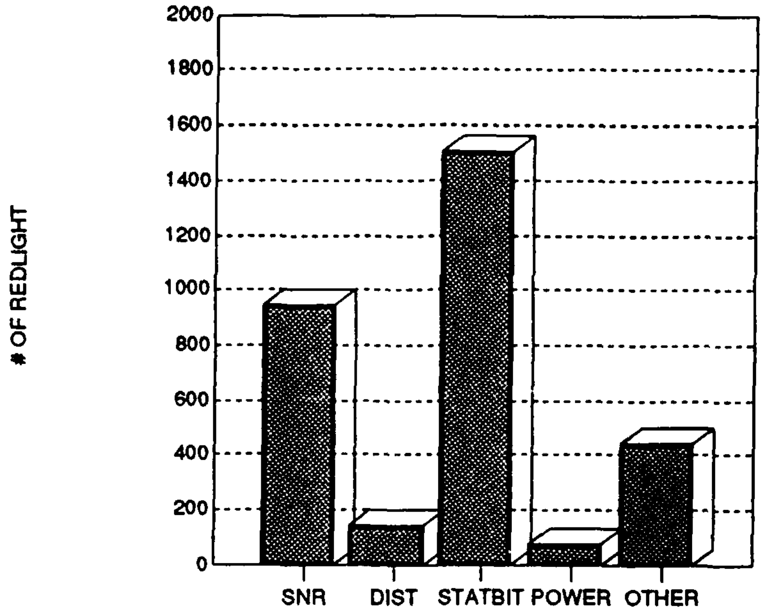
> **In approach mode, the lack of adequate navigational signals or sources shall be annunciated by means of a flag display on the primary navigational display. In other modes, an appropriately located annunciator may be used to satisfy this requirement.**

Paragraph 2.2.1.10 (b)(2) also states:

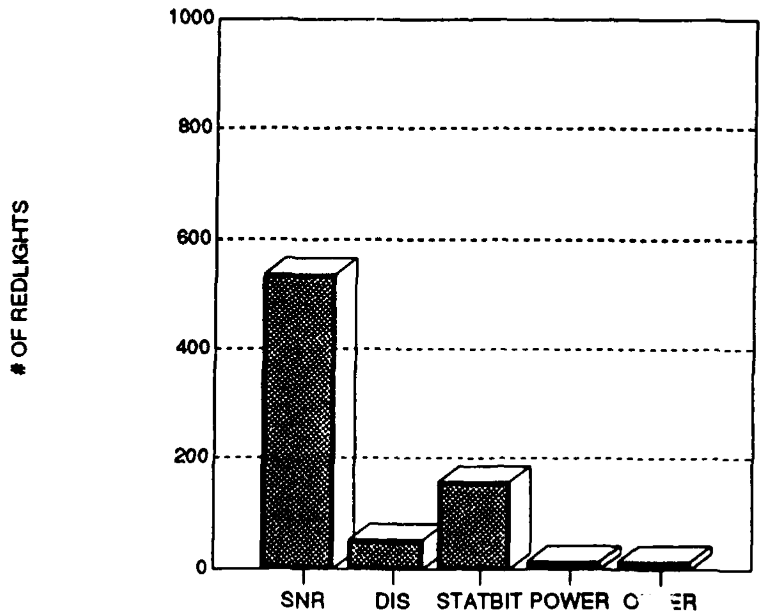
> **Loss of signal - The equipment shall detect loss of signal within 30 seconds for en route and terminal operation and ten seconds for approach.**

This suggests that a pilot on approach directly detects a momentary outage of 10 seconds or greater, thus making it unnecessary for a monitor system to take action during a status alarm. To increase the probability of the airborne receiver's detecting the outage, the USCG should mandate that momentaries have a minimum duration of 30 seconds. If the FAA monitor detects an outage of several minutes, it should register an alarm. When the transmitter is back in service, the monitor should automatically recover.

Figure 4-1. Hanscom Red Lights.



1986 HANSCOM REDLIGHTS



1987 HANSCOM REDLIGHTS

Figure 4-2. Comparative SNR Limits, Portland.

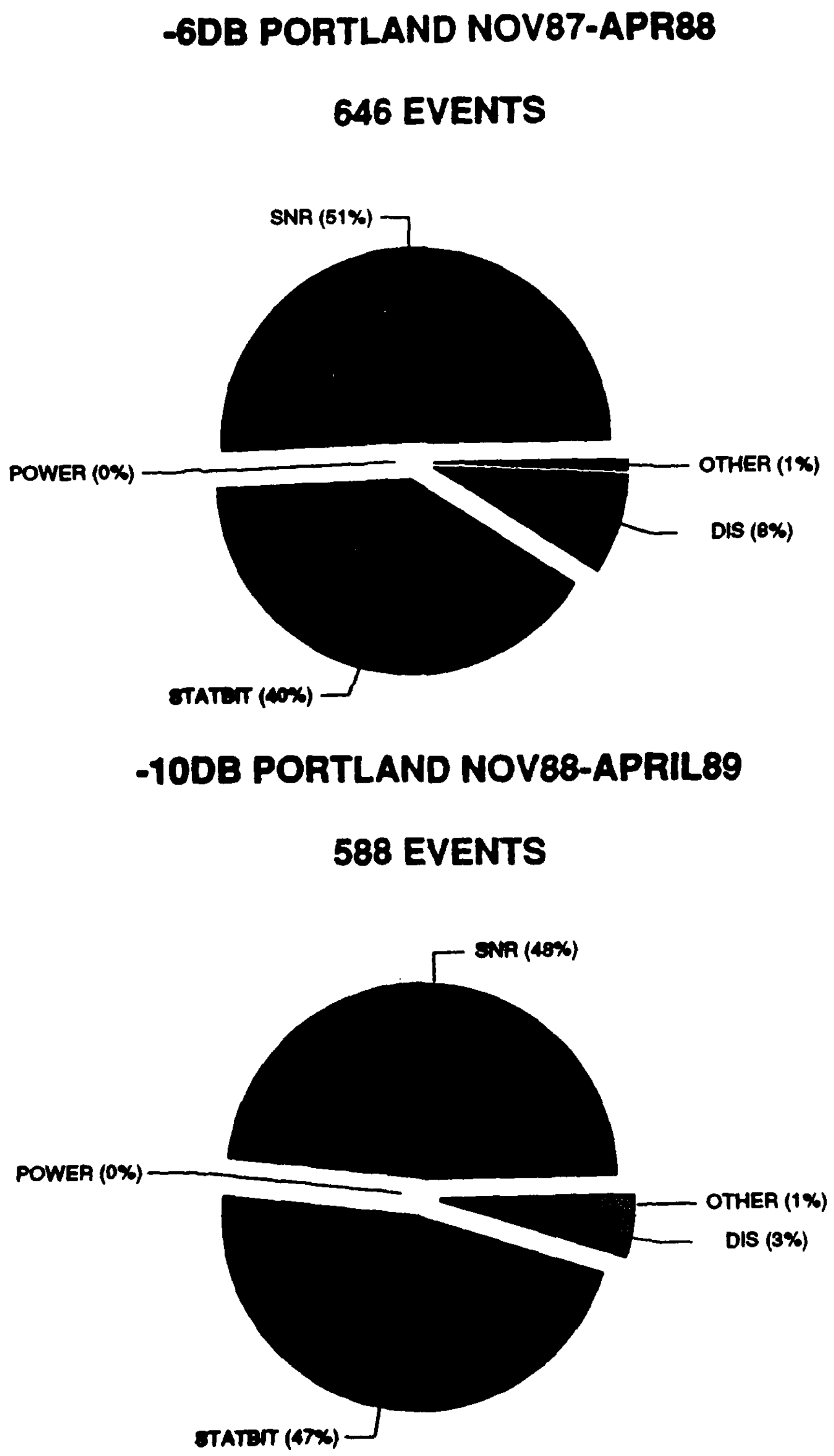
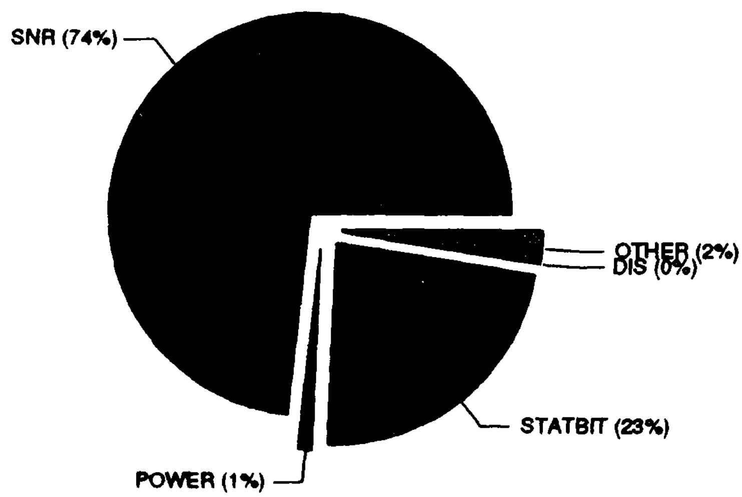


Figure 4-3. Comparative SNR Limits, Lakefront.

-6DB LAKEFRONT NOV87-APR88

863 EVENTS



-10DB LAKEFRONT NOV88-APR89

730 EVENTS

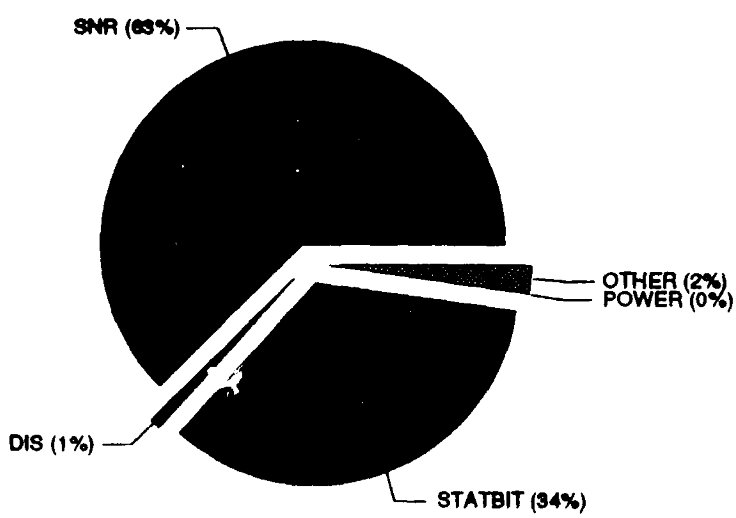


Figure 4-4. Total EIP Alarms Recorded (1989).

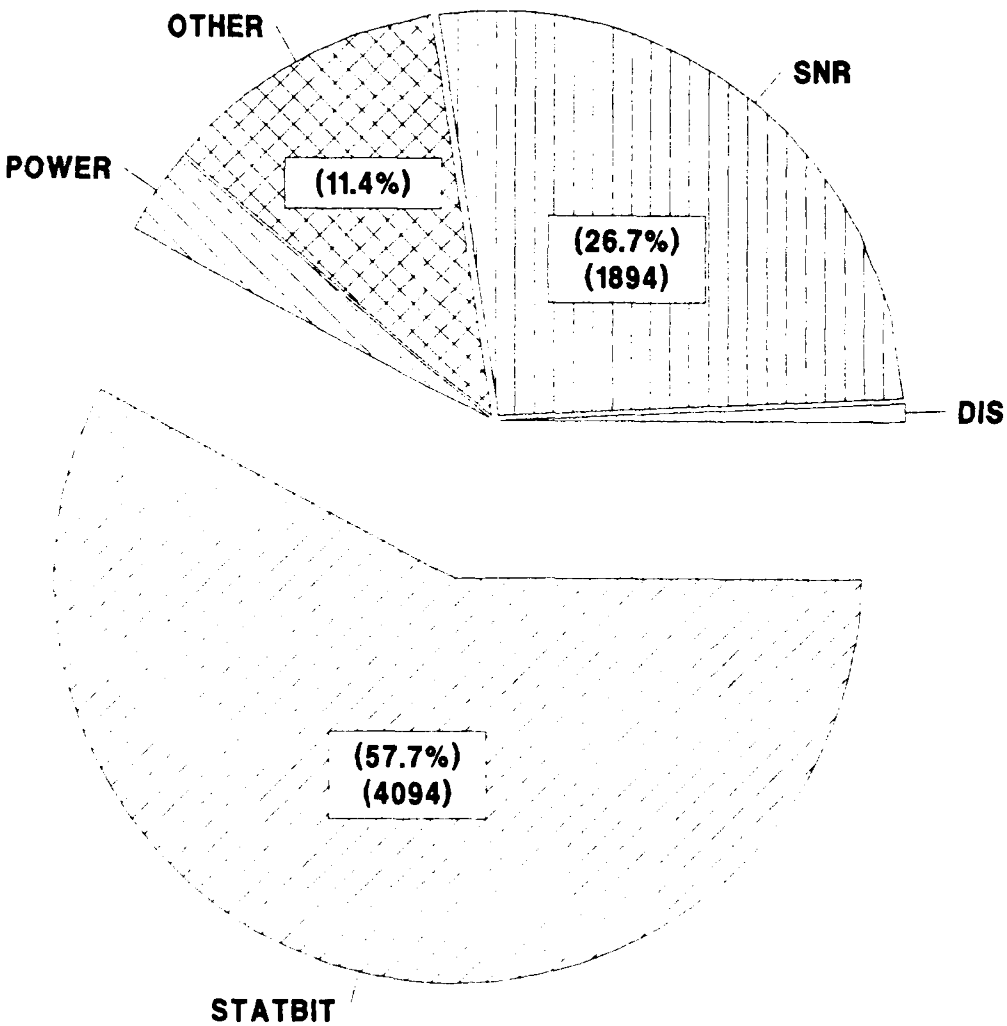
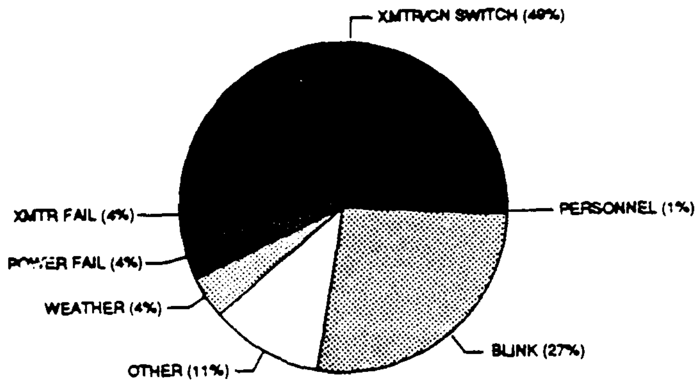
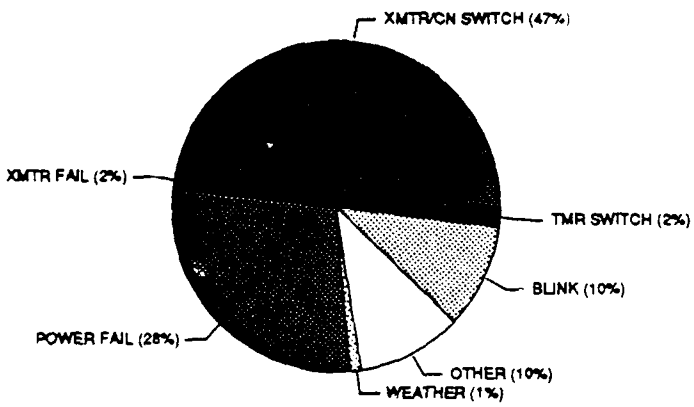


Figure 4-5. 1989 Northeast Chain Momentaries.

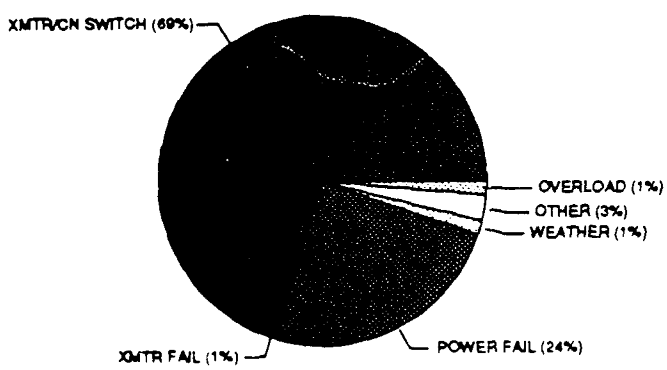
1989 SUMMARY OF MOMENTARIES (322)
NORTHEAST CHAIN(9960) - SENECA(M)



1989 SUMMARY OF MOMENTARIES (107)
NORTHEAST CHAIN(9960) - CARIBOU(W)



1989 SUMMARY OF MOMENTARIES (78)
NORTHEAST CHAIN(9960) - NANTUCKET(X)



5.0 EIP IMPACT ON FAA LORAN PROGRAM

Operation of the EIP monitor network has furnished the FAA with critical technical skills to develop system specifications for components of the Loran system. This section discusses the impact of the EIP on the design, siting and the function of the operational monitors.

5.1 Loran Operational Monitor System

The design of the EIP monitor stipulated the functions that it would perform. It was to be a real-time monitor that guaranteed that the signal in space would guide the pilot to the airport and keep the aircraft within the protected corridor. It was also to be a data collector that provided information on operation and control of the Loran system. The experience gained with the EIP monitor and operating the network produced a solid technical background for specifying the operational monitor.

5.1.1 Operational Monitor Design Characteristics

The major event uncovered during the EIP was that the operational monitor didn't require a new receiver design. There were at least 3 sophisticated off-the-shelf units available: enough to create a competition for the monitor contract. The operational specification was produced from a compilation of the specifications of available receivers and important conclusions from the EIP. To prevent the elimination of any receiver from the competition, the least restrictive of the receiver operating values were chosen. The operational monitor included a signal simulator to permit remote certification and eliminate a restrictive element found in the EIP. In addition the unit will operate through the VORTAC facility central processing unit thereby reducing the monitor acquisition problem.

The primary operational monitor software functions derived from the EIP experience were: acquiring data, handling alarms, storing data, averaging the data, interpreting commands from a remote input device, certifying the receiver, configuring the receiver, and running remote diagnostics.

The receiver data acquisition function commands the Loran receiver to transfer the receiver data to the monitor's central processing unit. There the position vector is calculated from the known latitude and longitude of the monitor and the latitude and longitude data passed from the receiver. The receiver data (except for the latitude and longitude) and the calculated position vector are then passed on to the alarm handler function.

The alarm handling function compares the previous sample of data passed from the receiver data acquisition function to the parameter limits file. If any parameter exceeds its associated alarm limit, the alarm handler sets the appropriate bit of that sample's status word. If 7 of the last 10 samples exceeded the alarm limits, then the alarm handler stores in the alarm buffer the ECDs, TDs, SNRs, and position data from the last 120 samples from the 120 second file and the last 20 averages of the same data from the 20 minute file. In the EIP the receiver had no ECD readout capability. However, later studies done for the airborne receiver TSO proved the need for knowledge of this parameter. If a blink occurs for 10 seconds on one of the received secondary stations, the time of the occurrence is stored in the blink alarm file. Likewise stored in the blink alarm file, is the end time of blink. When an alarm limit is exceeded the receiver data is stored in the fault history file. In the EIP this file is the snapshot file. When no alarm limit is exceeded the data is stored in the pre-fault history file and the 120 second file.

When used with the receiver certification function, the alarm handler compares the receiver data to the alarm limits and passes the results to the Loran monitor certification results file. In this mode, the alarm archive function is disabled.

The data archive function manages the storage and retrieval of data in the 120 second file, 20 minute file, 4 hour file, 60 day file and alarm files.

The data averaging function averages data stored in one file for storage in another.

The interpreting function translate commands input from the local input terminal, from the VORTAC central processor, and the units front panel interface, and calls the appropriate program function to execute the command.

There was no certification procedure for EIP. The staff compared the input parameter files with recorded initial settings and the forecast values. There may not be an operation requirement to certify the monitor system although the function exists. The certification function supervises the receiver certification process. A command to initiate certification arrives through either external port. The certification function turns on the simulator, connects the simulator to the receiver through the antenna coupler, calculates the Loran offset values from the parameter file and Loran monitor certification setup file and passes these values to the simulator. The receiver data acquisition function then passes the resulting data from the receiver through the alarm handler function, through the data archive, to the Loran monitor results file for access from the central processor unit or local input terminal.

The receiver configuration function allows examination of the receiver input spectrum (30 kHz either side of 100 kHz) to locate potential sources of interference and permits setting of the 4 notch filters to suppress any local interference. In the EIP this was done on site during the installation of the unit. Interfering signals not present during installation were not blocked. The receiver configuration function also selects the desired GRI and secondary stations.

The systems diagnostics function runs 2 types of monitor self-tests. One tests in the background during normal operation, while the other tests in an "off-line" mode. The off-line test does the same checks as the "background" one, but is much faster, since it runs without interruption.

Testing includes: receiver and simulator self-diagnostics, the watch-dog timer function, checks for Read-Only Memory (ROM) and Random Access Memory (RAM), and input/output.

5.1.2 System Operation and Control

The EIP and operational monitors are data collectors that provide information on control and operation of the Loran system. The critical discovery in the operation of the Loran transmitting system is the need to blink the system when it is operating outside specified values. Current operating procedures require the watch-stander to observe the signal for one minute before taking corrective action. TD limits are 0.10 to 0.15 microseconds. These limits are conservative, but the time is critical. The FAA requires the generation of a blink signal in 10 seconds whenever the signal drifts beyond 0.5 microseconds. The FAA does not permit an NPA in an area with a GDOP greater than 3000 feet/microsecond or a signal weaker than -6 db. Therefore a 0.5 microsecond absolute limit insures either that an aircraft will be within the protected corridor or the signal will be blinking.

5.1.3 Monitor Siting

Locating the Loran monitors at VORTAC sites proves very beneficial. The collocation rules out the need to identify, survey, and acquire sites for hundreds of Loran receivers. The service point, however, needs some form of communications link to the receiver. Loran data is collected by the receiver, but computer access to the receiver is needed to download data and for remote insertion of Loran parameters at the site.

The reasons VORTAC sites proved to be the best for monitor siting were the following:

1. Minimal signal interference of electronic equipment.

2. Commonality of VORTAC design, providing a standardized installation for the monitors (making installation cost effective).

3. Integration of Loran system into VORTAC's already dedicated communications network and its present traffic management system.

Loran and VORTAC systems are quite compatible: both are computer controlled and serviced by dedicated data communications. VORTAC monitor siting eliminates many costs. Personnel assigned to service the VORTAC sites can be shared, since the only difference in procedure is the response to additional alarm conditions of the Loran input. It should be noted that a Loran receiver antenna does not interfere with either a VOR or TACAN/DME since they operate in a much higher frequency band 108-118 mHz for VOR and 960-1215 mHz for TACAN/DME verses the 90-110 kHz for Loran.

Studies on the range of number of monitors required showed that a minimum of 29 monitors were needed (one for each of the 29 CONUS triads); since there were more than 5000 public use airports, a maximum of 5000 monitors would certainly cover the CONUS. In order to reduce the number of Loran monitors and retain redundant coverage, existing USCG data was analyzed along with data from 5 FAA signal monitors.

The conclusion was reached that local area effects of the Loran signal were constant up to a radius of 90 nm, or an area of approximately 25,447 square nm. On that basis, the FAA purchased 212 Loran monitors for CONUS and Alaska. This 90 nm radius was also supported by the 8-monitor network deployed across the CONUS in the EIP. Three supporting sources included the Ohio University operation of 2 monitors (in their Loran monitor correlation study) over a 92 nm baseline, ARNAV Inc.'s 2 receivers on an 85 nm baseline in Oregon, and FAATC airborne data collected by flying 6 flight paths across CONUS.

NFOLDS has developed the Airport Monitor Management System (AMMS) which determines if the signal variation pattern at a monitor site is applicable for any airport within a 90 nautical mile radius of the monitor. Before Loran can be used for an NPA, proper geometry and SNR requirements must be met. Also the triad that is satisfied for the airport must be monitored by one of the Loran monitors.

The AMMS gives the user information such as airports which lie outside the valid 90 nautical mile radius of a monitor site, airport monitor combination for an airport which provides the best triad coverage, or all the airports having no monitor coverage. The Airport Screening Model (ASM) is integrated into

the AMMS to identify the Loran triads that satisfy the minimum SNR and geometry requirements.

5.2 Related Studies

The FAATC and TSC conducted studies on the performance of current airborne receivers. RTCA, with the help of these and other studies, in turn devised MOPS for the aviation community to use with Loran. These studies were motivated by the lack of standards or procedures for the design and installation of Loran equipment in aircraft for the EIP users.

5.2.1 FAATC and TSC Airborne Receiver Studies

In 1985, the FAATC was asked to make recommendations for Loran receiver MOPS for NPAs, based on the performance of available Loran receivers. Tests were conducted at airports in the United States using fixed wing and rotary wing aircraft. The main issues of the FAATC study were SNR, ECD, GDOP, FTE, CDI sensitivity and human factor efficiency.

A SNR value of -10 db was found to be satisfactory for the acquisition and tracking of Loran signals in tests done at 6 US airports using 5 different Loran receivers. This value was decided upon because it aids quick detection of failure in the Loran transmitter. The lower the SNR, the longer it takes the receiver to detect a blink or an outage. The FAATC found the Loran signal acquisition and tracking function successful within the limit of +\- 4.2 microseconds ECD value.

The Flight Technical Error (FTE) was found to be satisfactory at +\- 1.25 nm full scale. Most receivers satisfy this criterion for sensitivity. A conclusion on the CDI update rate could not be reached.

Human factor efficiency involved 3 areas:

1. Triad identification.
2. Receiver operation after electrical power is restored.
3. Annunciation of receiver status.

It was decided to identify the 5 transmitters as master (M) and secondaries (W, X, Y, and Z). A receiver should not revert to the area calibration if the modes were previously selected before interruption of power. It was recommended that indication be provided when in the area calibration mode, approach mode, or in warning and advice status.

In 1987-88, TSC conducted a study on Loran airborne receiver design and performance characteristics. The study documented

techniques used by designers of the ANI-7000, Arnav R-40, Foster LRN500, Northstar M1, and II Morrow Model 612A. Functions covered in the report were signal acquisition, cycle identification and tracking, chain and station selection, navigational solutions, interference rejection, atmospheric noise measurement, envelope to cycle difference measurement, TD and time of arrival measurement. Technical information was obtained from the manufacturers to supplement analysis.

An important function of a Loran receiver is its ability to acquire signals. The report provides a general definition of signal acquisition techniques and algorithms of the various Loran receivers. It also describes receiver tracking and cycle selections and examines two methods of identifying the third cycle (zero crossing point).

The report examines techniques the 5 Loran receiver designers used in the following areas:

1. Navigational solutions for translating TD values into latitude/longitude. Methods are defined and evaluated for their suitability, simplicity and accuracy.

2. Electromagnetic interference rejection, including detection of interfering signals and tuning notch filters to attenuate signal amplitude.

3. Design of notch filters and factors influencing their number in Loran receivers.

4. Atmospheric noise measurement. Identifies causes and effects of ECD on measurement accuracy.

5. Signal-to-noise measurement. SNR on the phase tracking servo time constant in the ANI-7000 receiver examined, and receiver SNR measurement techniques described (with emphasis on the ANI-7000).

Because of the authoritative nature of the study, participants in RTCA SC-137 had details of how several receiver designers implemented the aforementioned functions. This permitted a rapid and successful consensus to develop for the MOPS, which became the basis for TSO-c60B.

5.3.2 RTCA and MOPS

With Engen's directive to expand Loran's use as a NAS radionavigation aid, criteria for the certification of Loran equipment and NPA were needed. For the EIP, the FAA (ANS-104N) developed interim criteria for STC approval of the approach procedures, equipment and monitor site requirements. Appendix A shows the

criteria used during EIP and includes procedures for functional flight test evaluations of the NPAs.

These requirements sufficed for EIP operation, but with increasing Loran use and major advances in Loran equipment technology, performance standards had to be updated for Loran airborne receivers. RTCA SC-137 updated the then current standards: "RTCA/DO-159 - Minimum Performance Standards - Airborne Loran-A and Loran-C Receiving Equipment", October 1975. Capitalizing on the experiences of the aviation community (users, receiver manufactures, FAA representatives) and material in FAATC receiver studies and EIP studies, RTCA SC-137 produced "RTCA/DO-194 Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Loran-C Inputs" in November, 1986. The document includes standards for equipment characteristics useful to designers, manufactures and installers. It defines performance functions and features of Loran systems for en route, terminal and approach modes.

EIP was used to test and analyze how the adjustments in limits affected the performance of the monitor system. Studies focused on SNR, Distance error, and ECD effects. Adjustments to Loran equipment criteria were continued with a TSO evaluation team, capitalizing on continuing equipment improvements, FAA studies and EIP user experiences.

6.0 CONCLUSIONS

The EIP has been the FAA's means of introducing Loran into the NAS safely and efficiently. The experience gained through this project has enabled the FAA to effectively plan for the full scale implementation of Loran as well as GPS. The following are the principal conclusions which can be drawn from this report.

A program which introduces new technology and new procedures into the NAS can benefit from using a limited pilot project like EIP; both the agency and user community can gain experience in the operation and limitations of the system. The active involvement of outside groups such as NASAO and avionics manufacturers should be encouraged.

There is no need for real time monitoring of the Loran signal by the FAA. Four years of EIP data collection has shown no evidence of the "slow TD drift". Unless some anomolous propagation behavior is manifested at a new site by the operational Loran monitor network all alarm conditions can either be detected in the cockpit or by the USCG SAM network.

With minor modifications, the 56-day TD forecasts utilized by the EIP can be adapted by NFOLDS using the data collected by the operational monitor system.

The alarm history of the EIP demonstrates the necessity for a special USCG aviation blink procedure, preferably automated, in order for there to be widespread aviation use of Loran NPAs. The integrity requirements demand an immediate blink when aviation tolerances are exceeded.

7.0 RECOMMENDATIONS

The EIP, initiated in 1984, was the first step in the process of Loran integration. Today Loran is the established and accepted supplementary system for en route movement. It is also the basis for the current FAA program to open to NPAs 17,000 landing sites which otherwise are not programmed for instrument-aided approaches. The EIP gave the FAA and the Loran user community experience using Loran. The success of the entire Loran aviation program (particularly the EIP) depended upon the active participation of many organizations inside and outside the FAA, with state officials acting through NASAO making major contributions. NASAO took the Loran message to their respective states. They identified users, classified 500 airports for the first set of Loran RNAV NPAs, and continue to provide leadership in acquiring congressional support for Loran.

This report recommends that the FAA/NASAO Loran Working Group carry on its efforts to bring a new vision to air navigation. Loran is already widely used and accepted as the official supplementary navigation aid. The first successful launches of the GPS satellite configuration have taken place. However, recent studies have conclusively shown that GPS cannot provide the signal availability and integrity necessary to meet the stringent sole-means aviation criteria even when all satellites are in position and working properly. It may be possible for the 2 systems to be complementary and provide sole-means 3-dimensional coverage. If studies determine that this route is feasible then no doubt it will also require large financial expenditures and involve extensive politics. NASAO adequately fills this role. New standards for Loran and its components will be developed to make system costs affordable and its implementation effective.

The manufacturers of Loran receivers contributed much technical expertise to the program. It is a long time policy to capitalize on the experiences of the aviation community (users, receiver manufacturers, FAA representatives) when avionics need standardization. In the EIP they produced "RTCA/DO-194 Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Loran-C Inputs" in November 1986. The document includes standards for equipment characteristics useful to designers, manufactures and installers. It defines performance functions and features of Loran systems for en route, terminal and approach modes.

This report recommends that the Loran Working Group be expanded to include technical expertise from the GPS area. This group would guide a requirements study for a mutually supportive

system. This report recommends the development of a comprehensive plan for the navigation system for the 21st century. In February 1983, the Office of Flight Operations of the FAA sponsored a 2-day conference of Government experts to develop the initial criteria for Loran approaches. The conference recognized the need to deal with the overriding issues of signal integrity, system performance assurance, and airworthiness standards. The FAA should convene a conference of Government experts to develop the initial criteria for the comprehensive plan.

The recommendations, in summary, are these:

1. Keep the Loran Working Group intact.

2. Expand its charter to include a vision of the navigation system of the 21st century.

3. Enlist the technical expertise of the GPS designers.

4. Convene a conference of Government experts to develop criteria and a plan to carry out this vision.

APPENDIX A

TECHNICAL GUIDANCE FOR STC APPROVALS OF LORAN RECEIVERS FOR EIP

A.1 General Criteria of Airport Certification for Loran NPAs

The FAA has agreed to assist NASAO in implementing a limited program to evaluate the feasibility of Loran NPAs at 8 U.S. airports. Key elements in this program are as follows:

1. At each approach location, a Loran monitor will be installed and its output will be remote either to the control tower or to the ATC facility clearing the aircraft for approach.

2. All runways used in the EIP have an existing instrument approach (mostly ILS) to be used as a control element in the evaluation; thus each Loran final approach course will overlie an existing final approach course which shall monitor Loran performance.

3. TSC (NFOLDS, DTS-502) will analyze all monitor TD values and provide a weekly calibration value to each selected operator.

A.2 Loran Approach Site Requirements

Each of the 8 selected airports will meet the following Loran performance requirements:

1. SNR shall be equal to or greater than 1:1 (0db).

2. ECD shall be equal to or less than +/- 2.4 microseconds.

3. GDOP shall be equal to or less than 3000 ft per microsecond.

A.3 Loran Receiver Requirements

Each installed Loran receiver must meet the following requirements:

1. **Airworthiness Standards.** Compliance with the airworthiness requirements for Loran systems for IFR operations in the NAS, specified in AC 20-121.

2. **Station Identification.** A means to identify and select

the Loran stations in use within a given GRI. Preferred display designations are M (master) and V, W, X, Y, Z (secondaries) for compatibility with the proposed approach plate station identification. Other means to certify the station may be acceptable.

3. **TD Correction.** A means to insert TD correction values in increments of .1 microsecond.

4. **Update Intervals.** It is desirable for receivers to update position and guidance information at one-second intervals or less. Larger update intervals (up to 4 seconds) will be eligible for evaluation.

5. **CDI Sensitivity.** The desired sensitivity of the Course Deviation Indicator should be +/- 1.25 nm (full-scale); however, for this program, sensitivity in the range of +/- 1.25 to +/- .6 nm (full scale) will be eligible for evaluation.

6. **Blink Detection.** Receivers must be able to detect blink within 10 seconds of the occurrence.

7. **Signal Loss Detection.** Receivers must be able to detect loss of signal within 15 seconds of occurrence.

8. **Lab Testing.** Receivers (hardware and software program) must have successfully completed the laboratory test conducted at the FAATC under the direction of ACT-140.

9. **Approach Accuracy Standards.** Receivers must meet these approach accuracy requirements of AC 90-45A:

System crosstrack error:		.3nm
Total crosstrack error:		.6nm
System along track error:	<=	.3nm
Total alongtrack error:	<=	.3nm.

A.4 Installation Criteria

Loran receivers must meet the following installation requirements:

1. Each selected participant should contact his local Aircraft Certification Office and submit an application for a STC or an amended STC (based upon the original IFR Loran en route approval by either field approval on FAA Form 337 or by STC).

2. Integration with the autopilot, the flight director, HSI, or other CDIs in the aircraft.

3. The Loran receiver may be a stand-alone system with its own dedicated CDI.

4. Have means for the pilot-not-flying to monitor the pilot flying the Loran approach. The pilot-not-flying must have the SIAP guidance on display in his primary field of view.

A.5 Functional Flight Test Evaluation

A typical flight test should include evaluations of:

1. **Operation.** Loran operating modes and procedures required to conduct NPAs.

2. **Interfaces.** Systems which interface with the Loran equipment. The following guidance is offered:

   a. If the Loran can be coupled to the autopilot, conduct 2 Loran approaches completely coupled to the Loran system. Construct a Loran route that includes the transition (feeder) fixes to the IAF, then the Final Approach Fix (FAF), MAP, and the missed approach holding point. At the FAF, begin a descent to the Minimum Descent Altitude (MDA) using the autopilot knob, vertical speed, or IAS hold. Level off at the MDA, and at 1 nm from the MAP, evaluate whether a safe landing can be made. Disconnecting the autopilot at that point and actually landing is recommended. On one approach, continue at MDA to the MAP and execute a coupled missed approach. Verify that the procedures, displays, and annunciation are satisfactory for conducting the published missed approach.

   b. If the Loran can be coupled to the flight director, conduct 2 approaches using only Loran guidance as in 2.a above.

   c. Fly 2 Loran approaches using raw data displayed on the Horizontal Situation Indicator (HSI), CDI, or Omnibearing Selector (OBS) indicator. FTE should be the largest on these approaches. At one mile from the MAP at MDA the aircraft must be in position from which a safe landing can be accomplished, and in each case a landing is strongly recommended.

   NOTE: Exceeding 30 degrees of bank to line up on the runway centerline is not recommended.

d. If the autopilot can be coupled to an ILS or localizer serving the same runway as the published Loran approach, it is recommended that at least two coupled ILS approaches be flown using the Loran as a monitor. From the FAF, approximately 1500 ft Above Ground Level, record Loran crosstrack information at about 200-foot increments (using the barometric altimeter as a reference) down to the decision height. This crosstrack data represents Loran system error (FTE is zero). If the MAP can be visually sited, quickly check distance to MAP at the MAP crossover point to determine the alongtrack error. Both crosstrack and alongtrack error should be less than .3 nm during the approach.

3. **CDI.** Pilots must evaluate the sensitivity of the CDI crosstrack data and qualitatively estimate FTE.

4. **Failure modes.** Pilots should simulate various failure modes (power loss, signal loss, etc.) and evaluate annunciations and the effects on the autopilot and flight director, if applicable.

5. **Crew workload.** PNFs should evaluate the crew workload when operating the Loran equipment. Emphasis should be on the PF's ability to conduct an impromptu Loran approach. Procedures include:

   a. Manual insertion and verification of correct GRI and triad.

   b. Manual insertion and verification that the proper TD correction is being used.

   c. Verification that the Loran system has not experienced a cycle slip by means of an acceptable procedure for making an accuracy check after the approved triad has been selected and is in use.

   d. Manual insertion and verification of the approved Loran approach waypoints transition fix, IAF, FAF, MAP, and the missed approach holding fix.

A.6 Airplane Flight Manual Supplement

IFR NPAs are approved only in accordance with the following conditions:

1. Compliance with SIAPs for Loran for Runway ______ at

______ airport.

2. SIAP (e.g., ILS/LOC, etc.) for Runway _____ at _____ airport is used as a monitor of Loran performance by the PNF.

3. The approved Loran triad has been selected and is in use prior to intercepting the final approach course.

4. The current area calibration value (provided by TSC) has been entered into the Loran receiver prior to intercepting the final approach course.

5. A satisfactory Loran accuracy check has been made no later than the final approach fix inbound.

Loran NPAs are not authorized or must be discontinued under the following conditions:

1. The HSI/CDI or OBS indicator displays a NAV warning flag.

2. The Loran receiver displays any warning that indicates degraded or unreliable Loran performance.

3. The navigation source (ILS, LOC, etc.) used as a monitor indicates a failure or unreliable data.

4. The navigation source used as a monitor indicates deviation from SIAP.

These additional normal procedures are recommended when amending the previously approved Loran Airplane Flight Manual Supplement:

1. Loran SIAPs are approved as the primary means of navigation provided the standard navigation source used as a monitor is tuned and operable.

2. If the Loran receiver fails during a Loran approach in Visual Meteorological Conditions, the approach can be continued using the standard navigation source. Any discrepant Loran accuracy or performance information should be recorded and reported to the local FAA Flight Sector Director's Office.

3. Loran accuracy checks are required prior to conducting a Loran approach. This test must be conducted on an approach triad after the area correction value has been inserted into the receiver. This accuracy check is needed to verify that the cycle slip has not occurred. The Loran position should check to within 1 nm of the navigation reference (VOR, VORTAC, NDB, etc.).

APPENDIX B

EIP SOFTWARE MENUS AND FILE TYPES

The following figures illustrate the screened images of the important menus in the LASER software system employed by the Loran EIP. There are also samples of each of the three types of file printout.

Figure B-1. LASER EIP Main Menu.

WARNING: This facility is used in FAA Air Traffic Control. Loss of human life may result from service interruption. Any person who interferes with Air Traffic Control or damages or trespasses on this propery will be prosecuted under Federal Law.

< < < LASER top menu > > >

Choose one of the following by first letter:

Status menu ....display current Loran status.

Download menu .....choose to download a data file.

Controller menu ....change parameters for status analysis.

Receiver menu ....send commands to Loran receiver.

Maintance menu ....upload files or exit to DOS for system control.

Exit ....done witk system, hang up phone.

Choice: :by first letter, then hit [return]

The **Status menu** allows the operator to check the actual Loran receiver alarm status at the current time.

In the **Download menu**, the user is able to download log, average, or snapshot files. The log and average files listings contain data for two weeks prior and up to the current date; the snapshot file listing has the one hundred most recent "pictures" of red light alarms for that receiver.

The proceding three menus are password protected to prevent tampering!

The **Controller menu** can be used to to correct and/or update the conditions of the receiver's signal parameters (i.e., TD values, SNR, crossing angle, etc.).

The **Receiver menu** allows the user to manually power up the Loran receiver and adjust the trackinhg cycles of the receiver.

The **Maintenance menu** allows the operator of the system upload files to the receiver and to also manipulate or change the operating systems of the monitor (i.e., the clock, software, etc.).

Figure B-2. EIP Controller Menu.

1-GRI = 99400.000	4-SNR minimum = -6		
2-TDI = 122454.292	5-SNR minimum = -6	7-Gradient =634.1	9-Offset = 0.250
3-TD2= 28155.101	6-SNR minimum = -6	8-Gradient =2239.1	10-Offset = 0.250

11-Receiver time constant is 10

12-Radius = 1824' 13-Crossing angle = 116.5

15-Timeout : ENABLED

Station identifier for 16-TD1 = W 17-TD2 = X

Enter the number of the item to be changed ('Q' [return] to quit):

The control menu is used to update the parameters file which stores the current forecasted values and system limits. Access to this menu is password controlled. With access one can update the forecast or adjust the system limits by entering the item's corresponding number. Above is an example of the Portland, OR monitor's control menu.

1. The group repetition interval is the Loran chain or master identifier. It is used to calibrate the receiver's oscillator. The output TDs for the two baselines are corrected proportionally to the calibration.

2.&3. The time differences recorded hear are the current forecasted values. They are compared to received TDs to determine weather the system is within tolerance

4,5&6 The minimum signal to noise ratios are compared to received SNRs to determine if the available signal meets NPA requirements. The system alarms if the SNR estimated by the monitor receiver drops below the minimum. SNR is calculated using 20log(a/sigma) where the log is base ten, A is amplitude of the Loran signal at the tracking point and instantaneous readings of noise as detected after passing through the front end are assumed to have a Gaussian distribution with mean 0 and standard deviation sigma.

7&8 The gradient which refers to the spacing between lines of position are expressed in feet per microsecond. The values are used to determine the distance between the received and forecasted time differences.

9&10 The offsets are a root sum square of terms and constitutes the maximum probable difference between the monitor receivers offset from its expected reading and the airborne receivers offset from its expected reading. The monitors offset from its expected value is measured then the airborne receivers offsets are +/- before the system is determined to be within tolerance. The following terms are taken into consideration when setting the offset; receiver bias, receiver tracking response, grid ware (difference in Loran signal offsets due to the distance of the aircraft from the monitor), propagation model difference.

11. The receiver time constants were set to match airborne receivers.

12. The radius or distance error allowable is the radius of the circle within which the airborne time difference offsets must lie when converted to a distance offset. Used is the total error budget minus the maximum allowable airborne receiver error.

13. This the angle between the two vectors perpendicular to the lines of position and pointing in the direction of increasing time difference.

15 Allows control of re-initializing the monitor system after an error has occurred.

16.&17. A one letter identifier for each secondary.

Figure B-3. EIP Receiver Menu.

```
< < < Receiver Control menu > > >

89-10-03    10:10:16        0005 99399978 8007 12245316 8005 28155018

   1 - Power-up sequence ...... Restart receiver from power on condition

   2 - Enable cycle selection . Receiver will select proper tracking cycle

   3 - Enable cycle status ...... Receiver will check for proper tracking point

   4 - Disable cycle function .. Disable receiver cycle functions

Choose by number or enter raw receiver command ('Q' to exit) :
```

Figure B-4. Log File.

89-01-02 Southbend Airport, indiana

TIME	APPROACH STATUS	STS BITS	MASTER GRI	STS BITS	TD1	STS BITS	TD2
00:00:00*	Grn	8008	89700071	8004	33041493	8002	50346061
01:00:00*	Grn	C8008	89700074	8004	33041496	8003	50346047
02:00:00*	Grn	8007	89700066	8004	33041487	8002	50345997
03:00:00*	Grn	8007	89700072	8004	33041471	8002	50345990
04:00:00*	Grn	8008	89700079	8004	33041469	8002	50345979
05:00:00*	Grn	8008	89700069	8003	33041444	8001	50345968
06:00:00*	Grn	8007	89700071	8003	33041472	8002	50346006
07:00:00*	Grn	8007	89700068	8003	33041448	8002	50345966
08:00:00*	Grn	8009	89700068	8007	33041434	8007	50345939
10:00:00*	Grn	8009	89700063	8008	33041377	8007	50345948
11:00:00*	Grn	8009	89700072	8007	33041386	8008	50345949
12:00:00*	Grn	8009	89700070	8007	33041343	8007	50345914
12:46:07	Red Sts M	8160	89700057	8008	33041296	8008	50345857
12:48:38:	Grn	8008	89700065	8007	33041358	8007	50345927
13:00:00*	Grn	C8009	89700067	8007	33041354	8007	50345907
14:00:00*	Grn	8008	89700067	8007	33041392	8007	50345902
14:22:12	Red Sts M	8154	89700056	8007	33041674	8008	50346215
14:23:19	Grn	8008	89700065	8007	33041350	8007	50345861
15:00:00*	Grn	8009	89700069	8007	33041375	8007	50345910
16:00:00*	Grn	8008	89700078	8008	33041364	8007	50345936
17:00:00*	Grn	8009	89700075	8007	33041366	8007	50345917
18:00:00*	Grn	8008	89700072	8007	33041382	8006	50345904
19:00:00*	Grn	8008	89700069	8006	33041356	8005	50345941
20:00:00*	Grn	8009	89700072	8004	33041333	8004	50345913
21:00:00*	Grn	8008	89700070	8005	33041331	8003	50345909
22:00:00*	Grn	8007	89700076	8004	33041270	8003	50345903
23:00:00*	Grn	8007	89700072	8004	33041326	8002	50345860

Figure B-5. Average File.

89-01-05 Southbend Airport, Indiana

GRI

89700.000

TIME	SAMPLE SIZE	SNR	dGRI	ST DEV GRI	MIN SNR	MAX SNR	MIN GRI	MAX GRI
00:00	14331	7	0.067	0.00	7	9	0.06	0.08
04:00	14332	8	0.069	0.00	6	9	0.06	0.08
08:00	14247	8	0.068	0.00	8	9	0.06	0.08
12:00	14332	8	0.066	0.00	8	9	0.05	0.08
16:00	14337	8	0.065	0.00	7	9	0.05	0.08
20:00	14333	8	0.064	0.00	7	9	0.05	0.07

TD1

33041.238

SAMPLE SIZE	SNR	dTD1	ST DEV TD1	MIN SNR	MAX SNR	MIN TD1	MAX TD1
14331	4	0.053	0.03	3	5	-0.03	0.16
14332	4	0.059	0.02	3	7	-0.01	0.13
14247	7	0.066	0.02	5	8	-0.01	0.13
14332	6	0.118	0.02	5	7	0.04	0.19
14336	6	0.144	0.02	4	8	0.07	0.21
14333	4	0.153	0.02	3	7	0.05	0.17

TD2

50345.935

SAMPLE SIZE	SNR	dTD2	ST DEV TD2	MIN SNR	MAX SNR	MIN TD2	MAX TD2
14331	2	-0.051	0.02	1	4	-0.13	0.04
14332	3	-0.032	0.03	1	6	-0.12	0.05
14247	6	-0.023	0.02	4	8	-0.08	0.04
14332	6	0.053	0.06	2	7	-0.00	0.16
14335	4	0.058	0.04	3	6	-0.05	0.09

Figure B-6. Snapshot File.

88-09-13 23:40:07 Southbend Airport, Indiana

TIME	SAMPLE SIZE	SNR	dGRI	ST DEV GRI	SAMPLE SIZE	SNR	dTD1	ST DEV TD1	SAMPLE SIZE	SNR	dTD2	ST DEV TD2
23:30	60	8	0.045	0.00	60	4	-0.172	0.01	60	2	-0.166	0.01
23:31	59	8	0.049	0.00	59	4	-0.174	0.01	59	3	-0.166	0.01
23:32	60	8	0.048	0.00	60	4	-0.149	0.01	60	3	-0.140	0.01
23:33	59	8	0.050	0.00	59	4	-0.149	0.00	59	2	-0.154	0.02
23:34	60	8	0.050	0.00	60	4	-0.150	0.01	60	3	-0.136	0.02
23:35	60	8	0.049	0.00	60	4	-0.160	0.01	60	3	-0.158	0.01
23:36	60	8	0.047	0.00	60	4	-0.155	0.01	60	3	-0.142	0.01
23:37	59	8	0.048	0.00	59	4	-0.149	0.01	59	2	-0.155	0.02
23:38	60	8	0.048	0.00	60	5	-0.160	0.01	60	3	-0.151	0.01
23:39	60	8	0.048	0.00	60	4	-0.158	0.01	60	2	-0.171	0.01

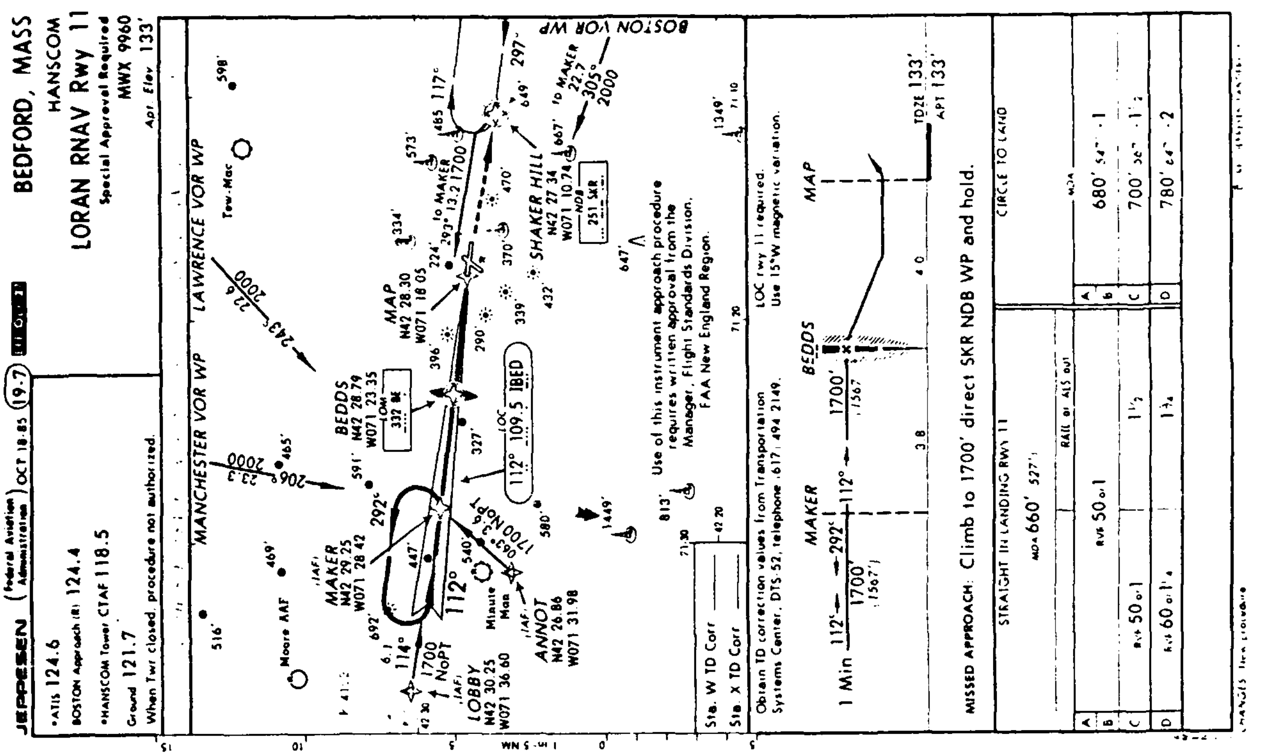
23:38:07	8008	89700056	8004	33041878	8003	50346764
23:38:08	8008	89700054	8004	33041880	8003	50346766
23:38:09	8008	89700055	8004	33041885	8003	50346767
23:38:10	8008	89700055	8004	33041885	8003	50346765

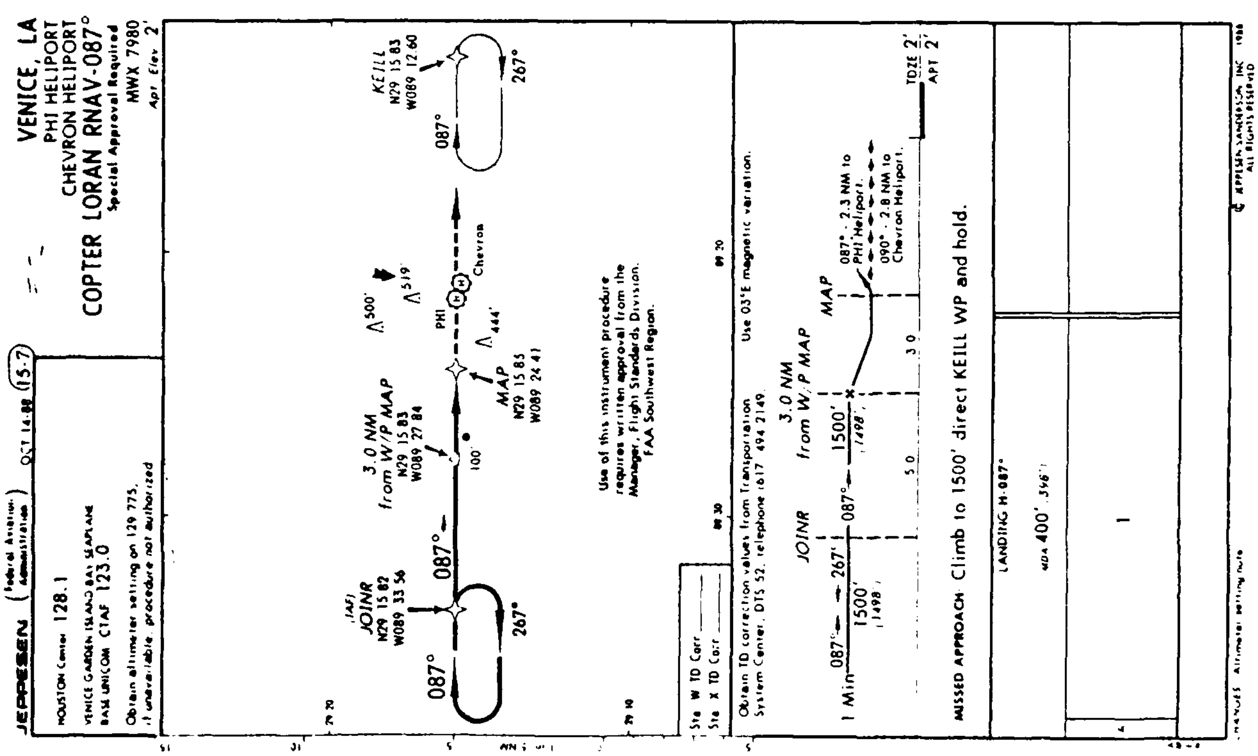
23:40:04	8008	89700051	8005	33041888	8002	50346735
23:40:05	8008	89700046	8005	33041896	8002	50346739
23:40:06	8008	89700046	8005	33041895	8002	50346743
23:40:07	8008	89700045	8005	33041893	8003	50346744

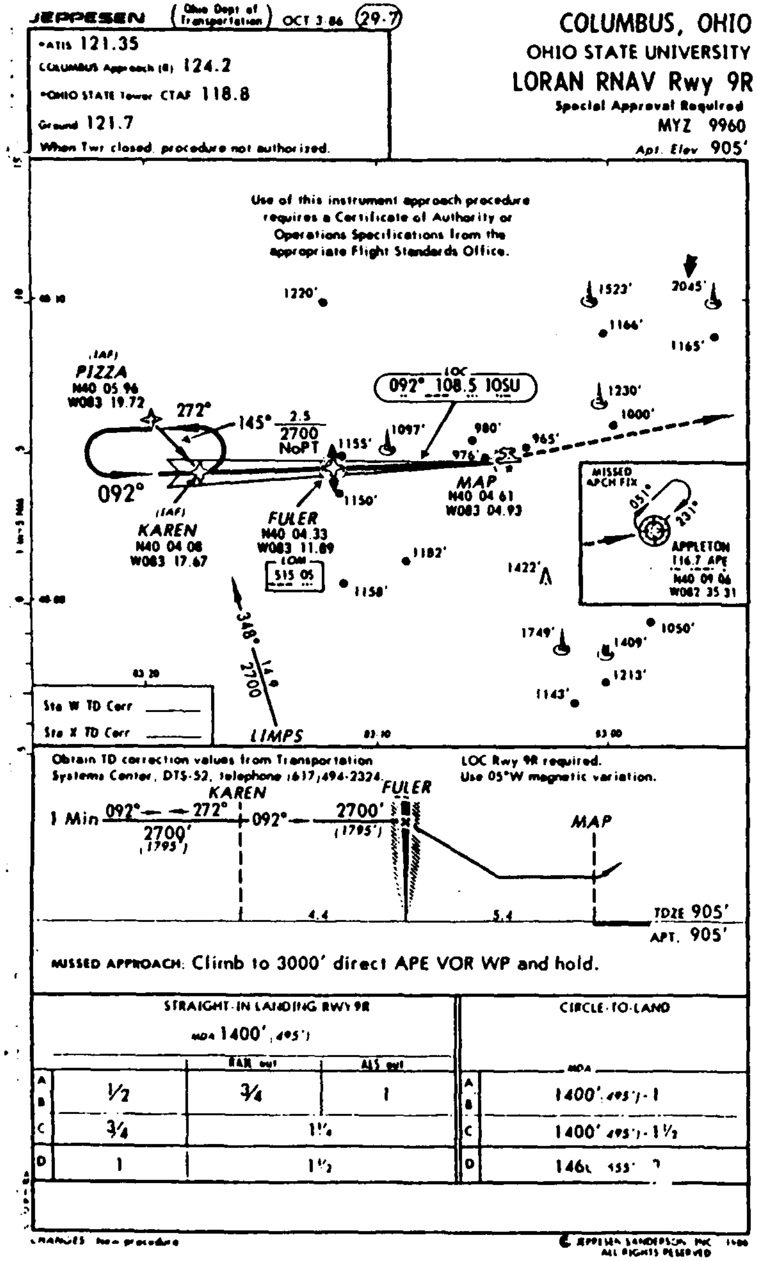
APPENDIX C

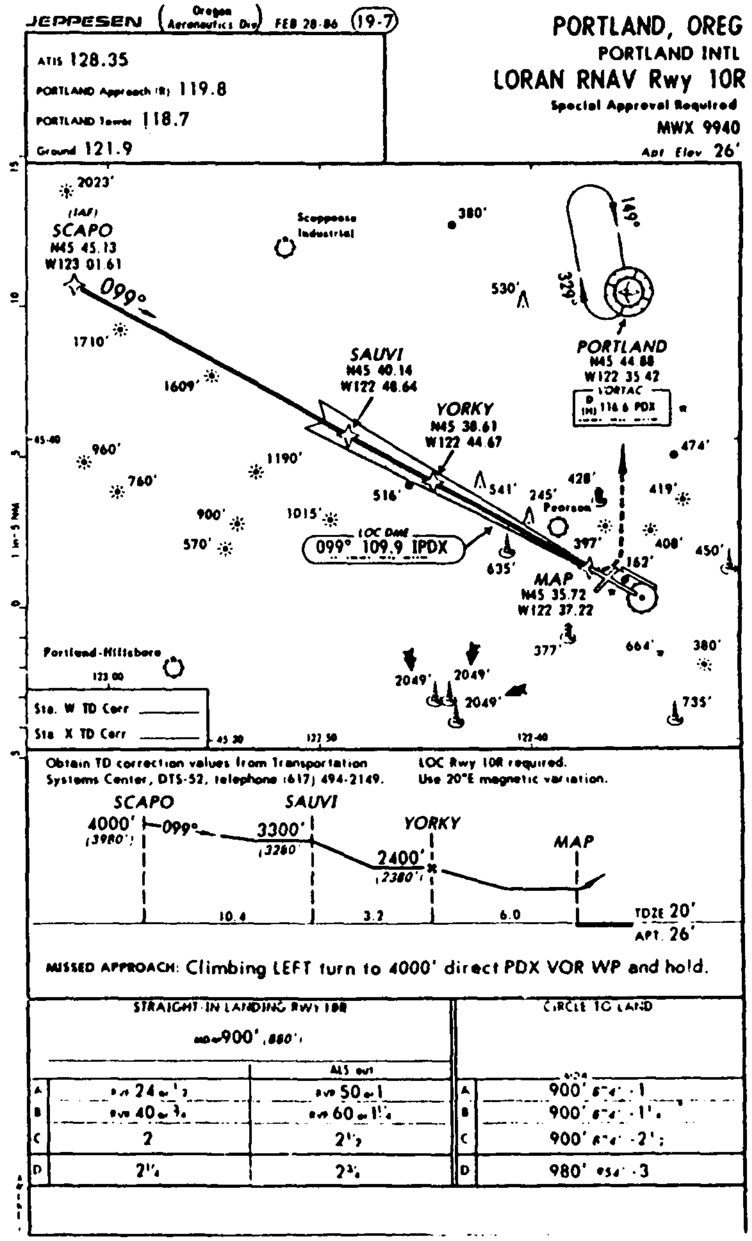
APPROACH PLATES

Use of instrument approach procedures requires written approval from the analysis of the Flight Standards Division for the specific region.


BEDFORD, MASS
HANSCOM
LORAN RNAV Rwy 11
Special Approval Required
MWX 9960
Apt Elev 133'
JEPPESEN
OCT 18-85
19-7
ATIS 124.6
BOSTON Approach (R) 124.4
HANSCOM Tower CTAF 118.5
Ground 121.7
When Twr closed, procedure not authorized.
MANCHESTER VOR WP
LAWRENCE VOR WP
BOSTON VOR WP
(IAF) MAKER
N42 29.25
W071 28.42
BEDDS
N42 28.79
W071 23.35
MAP
N42 28.30
W071 18.05
(IAF) LOBBY
N42 30.25
W071 36.60
(IAF) ANNOT
N42 26.86
W071 31.98
SHAKER HILL
N42 27.34
W071 10.74
LOC
112° 109.5 IBED
Use of this instrument approach procedure requires written approval from the Manager, Flight Standards Division, FAA New England Region.
Obtain TD correction values from Transportation Systems Center, DTS-52, telephone (617) 494-2149.
LOC Rwy 11 required.
Use 15°W magnetic variation.
MISSED APPROACH: Climb to 1700' direct SKR NDB WP and hold.
STRAIGHT-IN LANDING RWY 11
CIRCLE-TO-LAND
MDA 660' 527'
TDZE 133'
APT 133'


VENICE, LA
PHI HELIPORT
CHEVRON HELIPORT
COPTER LORAN RNAV-087°
Special Approval Required
MWX 7980
Apt Elev 2'
JEPPESEN
OCT 14-88
15-7
HOUSTON Center 128.1
VENICE GARDEN ISLAND BAY SEAPLANE BASE UNICOM CTAF 123.0
Obtain altimeter setting on 129.775, if unavailable procedure not authorized.
(IAF) JOINR
N29 15.82
W089 33.56
3.0 NM from W/P MAP
N29 15.83
W089 27.84
MAP
N29 15.85
W089 24.41
KEILL
N29 15.83
W089 12.60
PHI
Chevron
Use of this instrument approach procedure requires written approval from the Manager, Flight Standards Division, FAA Southwest Region.
Obtain TD correction values from Transportation System Center, DTS-52, telephone (617) 494-2149.
Use 03°E magnetic variation.
MISSED APPROACH: Climb to 1500' direct KEILL WP and hold.
LANDING H-087°
MDA 400' 398'
TDZE 2'
APT 2'

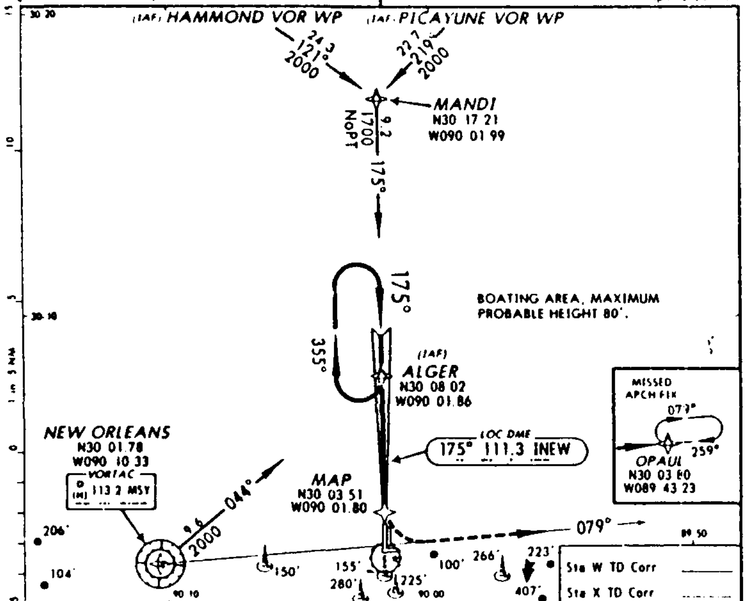

JEPPESEN (Ohio Dept of Transportation) OCT 3 86 29-7
COLUMBUS, OHIO
OHIO STATE UNIVERSITY
LORAN RNAV Rwy 9R
Special Approval Required
MYZ 9960
Apt. Elev 905'
ATIS 121.35
COLUMBUS Approach (R) 124.2
OHIO STATE Tower CTAF 118.8
Ground 121.7
When Twr closed, procedure not authorized.
Use of this instrument approach procedure requires a Certificate of Authority or Operations Specifications from the appropriate Flight Standards Office.
(IAF) PIZZA N40 05.96 W083 19.72
(IAF) KAREN N40 04.08 W083 17.67
FULER N40 04.33 W083 11.89
LOM 515 OS
MAP N40 04.61 W083 04.93
LOC 092° 108.5 IOSU
MISSED APCH FIX
APPLETON 116.7 APE N40 09.06 W082 35.31
LIMPS
Sta. W TD Corr
Sta. X TD Corr
Obtain TD correction values from Transportation Systems Center, DTS-52, telephone (617) 494-2324.
LOC Rwy 9R required.
Use 05°W magnetic variation.
TDZE 905'
APT. 905'
MISSED APPROACH: Climb to 3000' direct APE VOR WP and hold.
STRAIGHT-IN LANDING RWY 9R
MDA 1400' (495')
RAIL out
ALS out
CIRCLE-TO-LAND
MDA
1400' (495')-1
1400' (495')-1½
CHANGES: New procedure
© JEPPESEN SANDERSON, INC. 1986 ALL RIGHTS RESERVED


JEPPESEN (Oregon Aeronautics Div) FEB 28-86 19-7
PORTLAND, OREG
PORTLAND INTL
LORAN RNAV Rwy 10R
Special Approval Required
MWX 9940
Apt. Elev 26'
ATIS 128.35
PORTLAND Approach (R) 119.8
PORTLAND Tower 118.7
Ground 121.9
(IAF) SCAPO N45 45.13 W123 01.61
SAUVI N45 40.14 W122 48.64
YORKY N45 38.61 W122 44.67
PORTLAND N45 44.88 W122 35.42
VORTAC 116.6 PDX
MAP N45 35.72 W122 37.22
LOC DME 099° 109.9 IPDX
Scappoose Industrial
Portland-Hillsboro
Pearson
Sta. W TD Corr
Sta. X TD Corr
Obtain TD correction values from Transportation Systems Center, DTS-52, telephone (617) 494-2149.
LOC Rwy 10R required.
Use 20°E magnetic variation.
TDZE 20'
APT. 26'
MISSED APPROACH: Climbing LEFT turn to 4000' direct PDX VOR WP and hold.
STRAIGHT-IN LANDING RWY 10R
MDA 900' (880')
ALS out
CIRCLE-TO-LAND
980' (954')-3

JEPPESEN (Louisiana Dept of Transportation) SEP 5 86 (29-7)

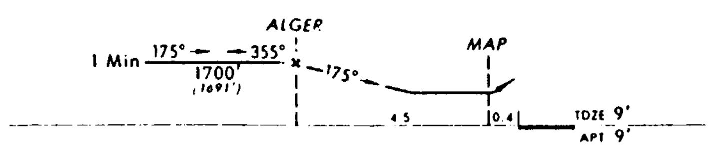
NEW ORLEANS, LA
LAKEFRONT
LORAN RNAV Rwy 18R
Special Approval Required
MWX 7980
Apt Elev 9'

ATIS 124.9
NEW ORLEANS Approach (R) North 120.6
South 123.85
*LAKEFRONT Tower CTAF 119.9
Ground 121.7
When Twr closed procedure not authorized



Obtain TD correction values form Transportation Systems Center, DTS-52, telephone (617) 494-2324

LOC Rwy 18R required.
Use 04°E magnetic variation.



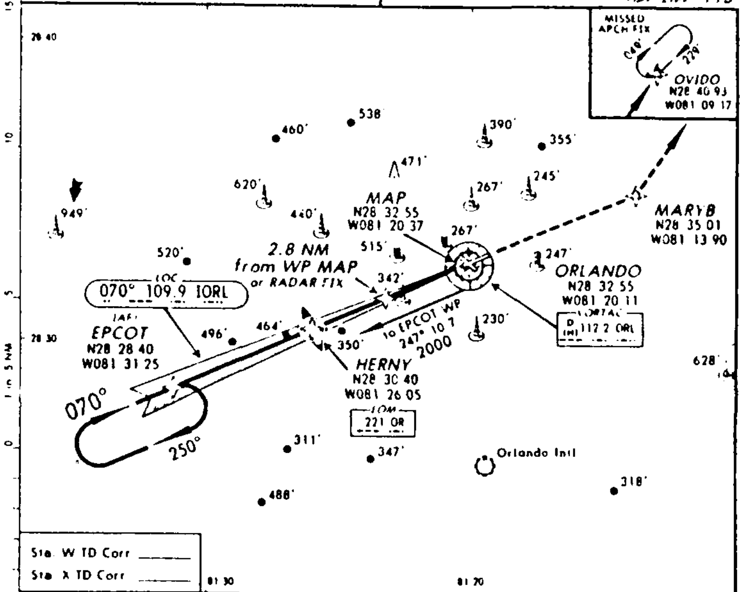
MISSED APPROACH Climbing LEFT turn to 2000' via outbound MSY VOR R-079 to OPAUL WP and hold.

STRAIGHT-IN LANDING RWY 18R				CIRCLE-TO-LAND
	MDA 340' (331')			
	FAIL out		ALS out	MDA
A	1/2	3/4	1	460' (451') -1
B	1/2	3/4	1	460' (451') -1
C	1/2	3/4	1	460' (451') -1½
D	1			600' (591') -2

JEPPESEN (Florida Dept of Transportation) JUL 11-86 (19-7)

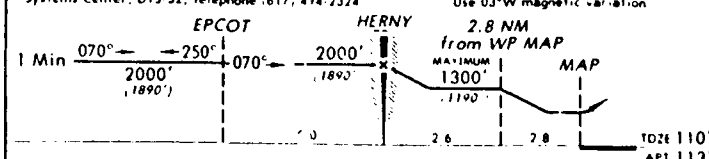
ORLANDO, FLA
ORLANDO EXECUTIVE
LORAN RNAV Rwy 7
Special Approval Required
MYZ 7980
Apt Elev 113'

*ATIS 127.25
ORLANDO Approach (R) 124.8
*EXECUTIVE Tower 118.7
Ground 121.4
ORLANDO Radio (AAS) CTAF 118.7 when Twr inop.
When Twr closed, procedure not authorized.



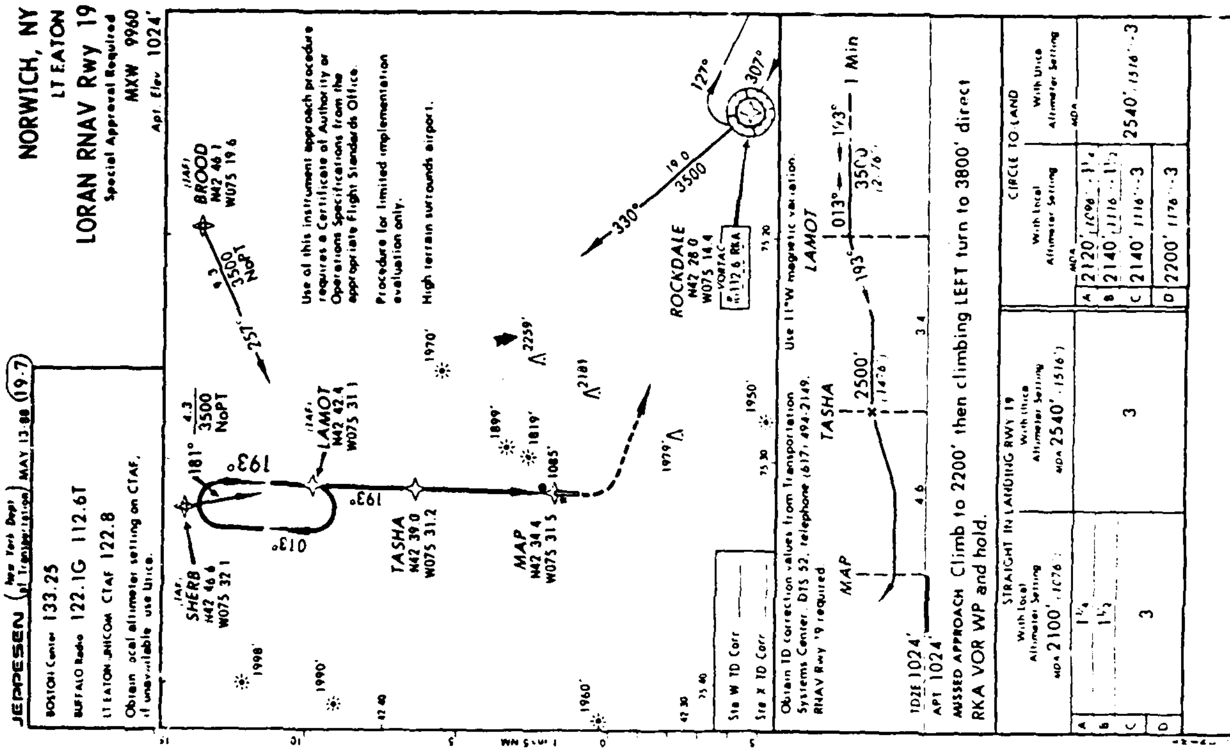
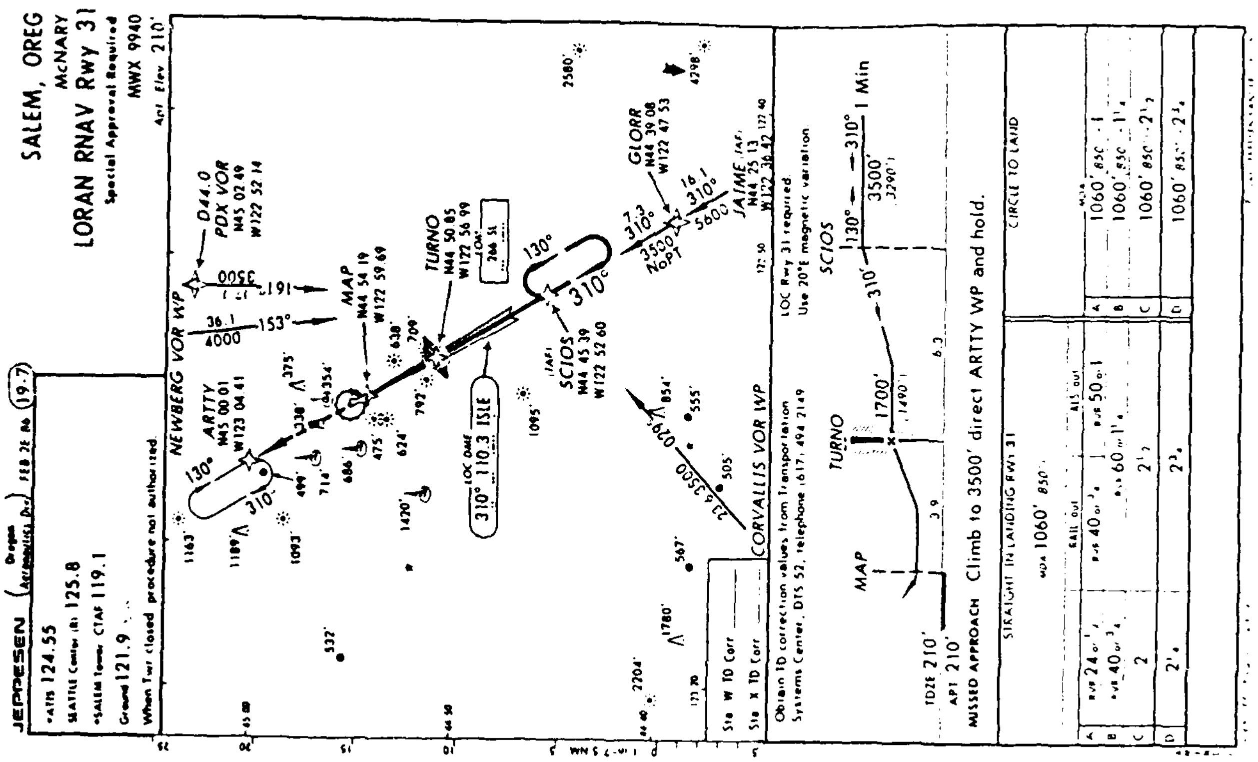
Obtain TD correction values from Transportation Systems Center, DTS-52, telephone (617) 494-2324

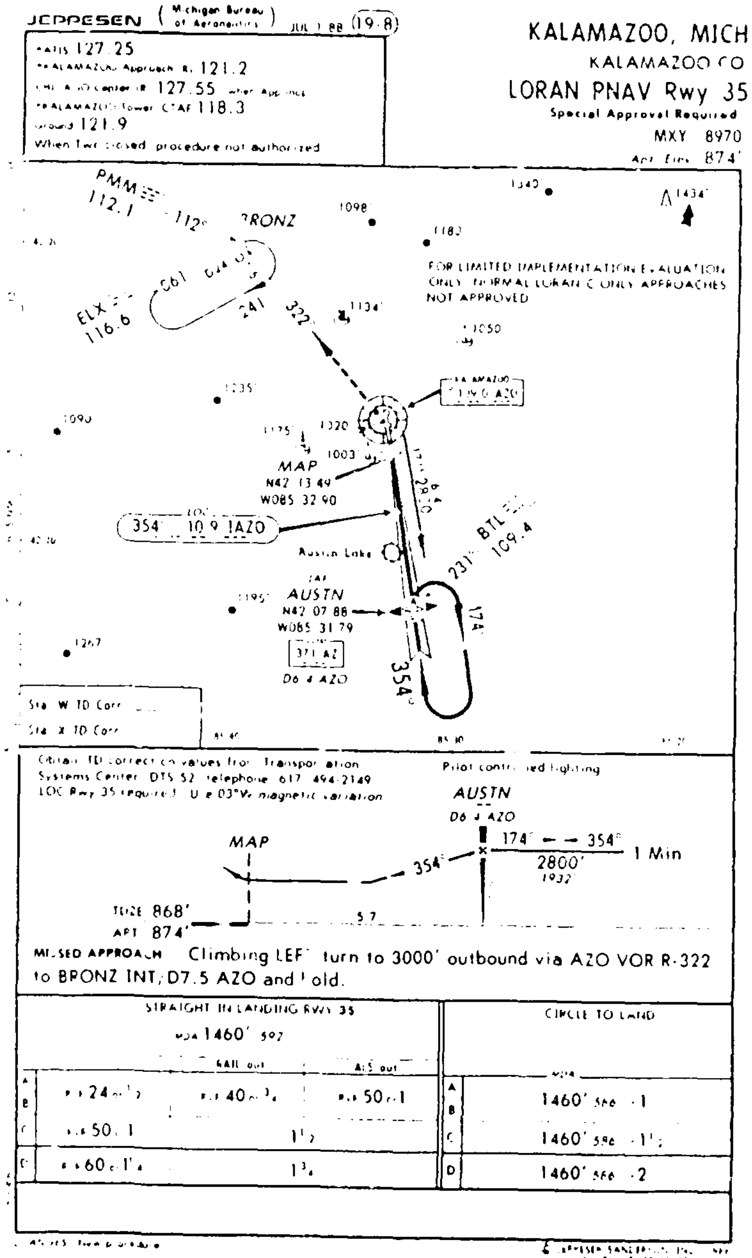
LOC rwy 7 required
Use 03°W magnetic variation

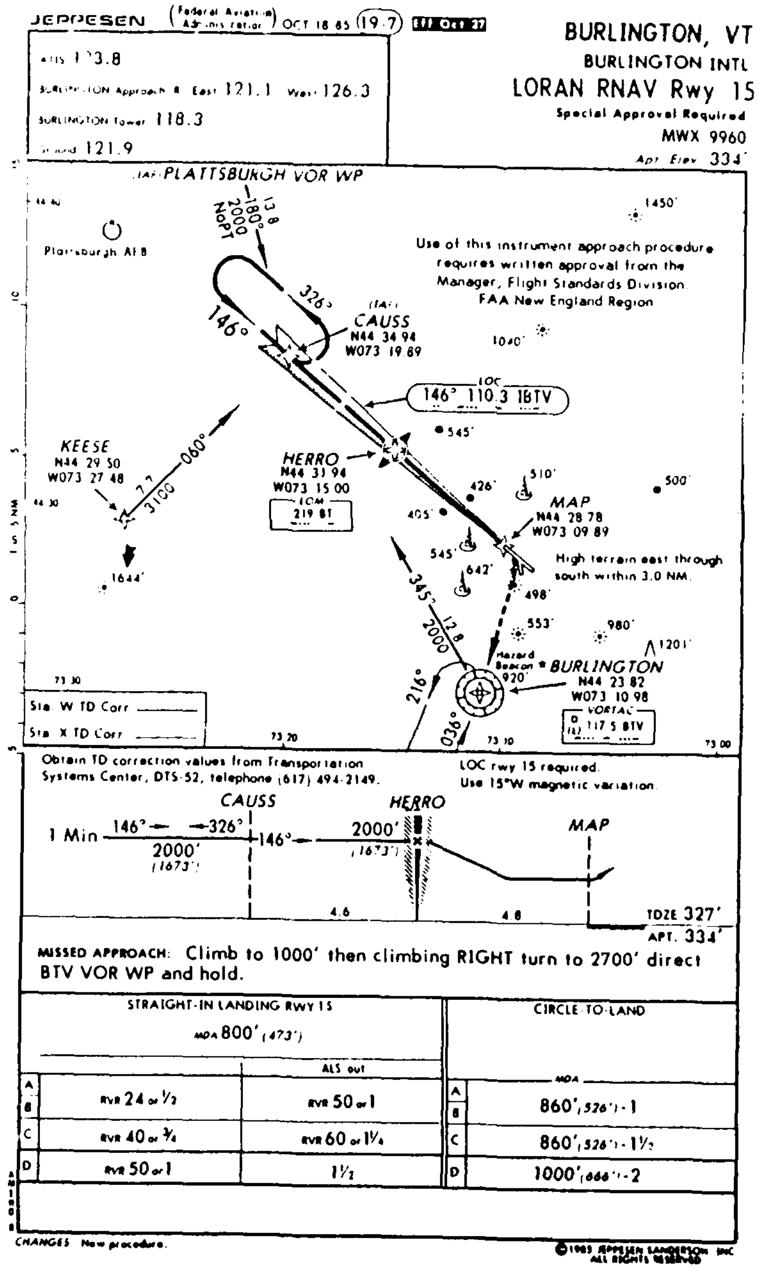


MISSED APPROACH: Climb to 1200' direct MARYB WP then climbing LEFT turn to 2000' direct OVIDO WP and hold.

STRAIGHT-IN LANDING RWY 7			CIRCLE-TO-LAND
	MDA 780' (670')		
		RAIL or ALS out	MDA
A	RVR 40 or 3/4	RVR 50 or 1	780' (667') -1
B	RVR 40 or 3/4	RVR 50 or 1	780' (667') -1
C	RVR 60 or 1¼	1¾	780' (667') -1¾
D	1½	2	820' (707') -2¼


NORWICH, NY
LT EATON
LORAN RNAV Rwy 19
Special Approval Required
MXW 9960
Apt Elev 1024'
BOSTON Center 133.25
BUFFALO Radio 122.1G 112.6T
LT EATON UNICOM CTAF 122.8
SHERB
LAMOT
TASHA
MAP
BROOD
ROCKDALE
Use of this instrument approach procedure requires a Certificate of Authority or Operations Specifications from the appropriate Flight Standards Office.
Procedure for limited implementation evaluation only.
High terrain surrounds airport.
MISSED APPROACH Climb to 2200' then climbing LEFT turn to 3800' direct RKA VOR WP and hold.
STRAIGHT IN LANDING RWY 19
CIRCLE TO LAND

SALEM, OREG
McNARY
LORAN RNAV Rwy 31
Special Approval Required
MWX 9940
Apt Elev 210'
SEATTLE Center 125.8
NEWBERG VOR WP
ARTTY
MAP
TURNO
SCIOS
GLORR
JAIME
CORVALLIS VOR WP
310° LOC DME 110.3 ISLE
MISSED APPROACH Climb to 3500' direct ARTTY WP and hold.
STRAIGHT IN LANDING RWY 31
CIRCLE TO LAND


JEPPESEN (Michigan Bureau of Aeronautics) JUL 1 88 (19-8)
KALAMAZOO, MICH
KALAMAZOO CO
LORAN PNAV Rwy 35
Special Approval Required
MXY 8970
Apt Elev 874'
127.25
KALAMAZOO Approach R 121.2
127.55
KALAMAZOO Tower CTAF 118.3
Ground 121.9
When Twr closed procedure not authorized
PMM 112.1
BRONZ
ELX 116.6
322°
1098
1182
1343
1434'
FOR LIMITED IMPLEMENTATION EVALUATION ONLY. NORMAL LORAN C ONLY APPROACHES NOT APPROVED
1134'
1050
1235
1090
1020
1003
MAP
N42 13 49
W085 32 90
354° 109 IAZO
Austin Lake
BTL 109.4
231°
AUSTN
N42 07 88
W085 31 79
D6 4 AZO
354°
174°
1195
1267
Sta W TD Corr
Sta X TD Corr
Pilot controlled lighting
AUSTN
D6.4 AZO
MAP
174° 354°
2800'
1 Min
354°
TDZE 868'
APT 874'
5.7
MISSED APPROACH: Climbing LEFT turn to 3000' outbound via AZO VOR R-322 to BRONZ INT/D7.5 AZO and hold.
STRAIGHT-IN LANDING RWY 35
MDA 1460' 592
CIRCLE TO LAND
1460'
1460'
1460'


JEPPESEN (Federal Aviation Administration) OCT 18 85 (19-7)
BURLINGTON, VT
BURLINGTON INTL
LORAN RNAV Rwy 15
Special Approval Required
MWX 9960
Apt Elev 334'
BURLINGTON Approach R East 121.1 West 126.3
BURLINGTON Tower 118.3
Ground 121.9
PLATTSBURGH VOR WP
13.8
180°
2000
NoPT
Plattsburgh AFB
1450'
Use of this instrument approach procedure requires written approval from the Manager, Flight Standards Division, FAA New England Region
326°
CAUSS
N44 34 94
W073 19 89
146°
1040'
146° 110.3 IBTV
545'
KEESE
N44 29 50
W073 27 48
060°
3100
HERRO
N44 31 94
W073 15 00
LOM
219 BT
426'
510'
500'
MAP
N44 28 78
W073 09 89
405'
545'
642'
High terrain east through south within 3.0 NM.
498'
1644'
345°
12.8
2000
553'
980'
1201'
216°
BURLINGTON
N44 23 82
W073 10 98
VORTAC
117.5 BTV
036°
Sta W TD Corr
Sta X TD Corr
Obtain TD correction values from Transportation Systems Center, DTS-52, telephone (617) 494-2149.
LOC rwy 15 required.
Use 15°W magnetic variation.
CAUSS
HERRO
MAP
1 Min
146°
326°
146°
2000'
(1673')
2000'
(1673')
4.6
4.8
TDZE 327'
APT. 334'
MISSED APPROACH: Climb to 1000' then climbing RIGHT turn to 2700' direct BTV VOR WP and hold.
STRAIGHT-IN LANDING RWY 15
MDA 800' (473')
CIRCLE-TO-LAND
ALS out
MDA
RVR 24 or 1/2
RVR 50 or 1
860' (526') - 1
RVR 40 or 3/4
RVR 60 or 1 1/4
860' (526') - 1 1/2
RVR 50 or 1
1 1/2
1000' (666') - 2
CHANGES: New procedure.
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JEPPESEN (Oregon Aeronautics Div) FEB 28 '6 (19-7)

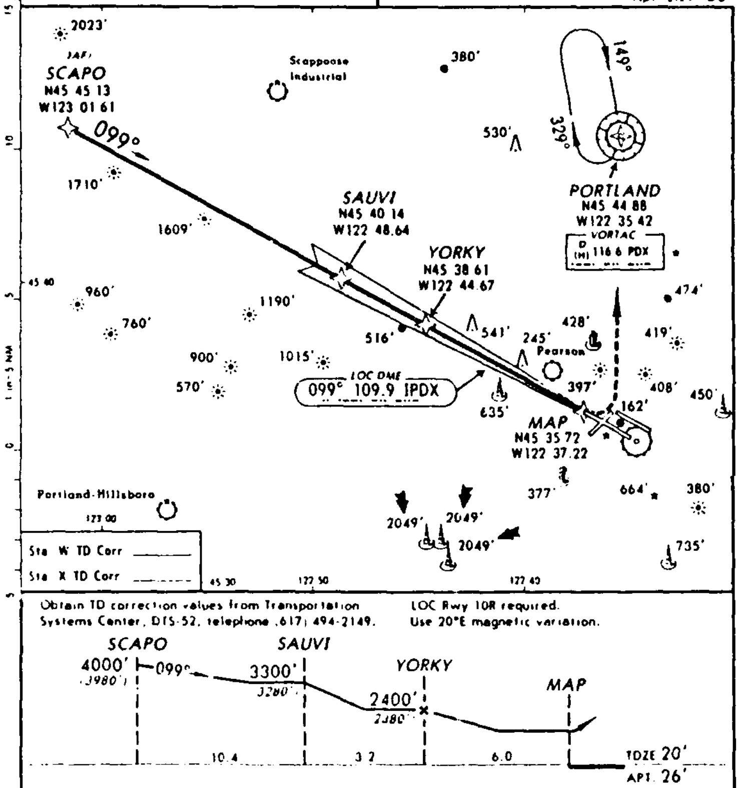
ATIS 128.35
PORTLAND Approach (R) 119.8
PORTLAND Tower 118.7
Ground 121.9

PORTLAND, OREG
PORTLAND INTL
LORAN RNAV Rwy 10R

Special Approval Required

MWX 9940

Apt Elev 26'



MISSED APPROACH Climbing LEFT turn to 4000' direct PDX VOR WP and hold.

	STRAIGHT-IN LANDING RWY 10R MDA 900' (880')	ALS out		CIRCLE-TO-LAND MDA
A	RVR 24 or 1/2	RVR 50 or 1	A	900' (874') - 1
B	RVR 40 or 3/4	RVR 60 or 1 1/4	B	900' (874') - 1 1/4
C	2	2 1/2	C	900' (874') - 2 1/2
D	2 1/4	2 3/4	D	980' (954') - 3

Reeve Aleutian Airways NOV 25-88 (19-7)

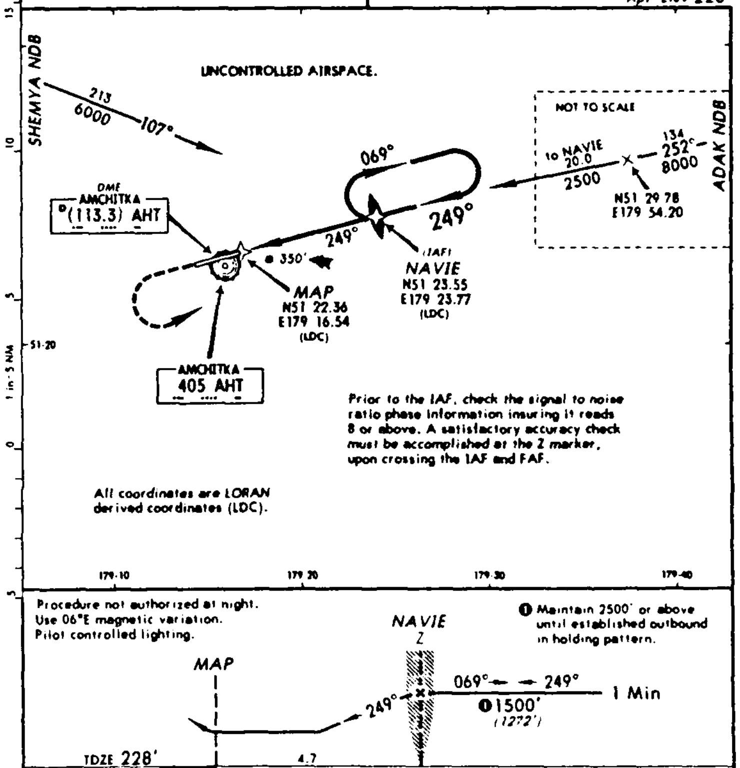
ANCHORAGE Center 128.2
AMCHITKA Radio CTAF 122.8
Obtain local altimeter setting on CTAF; if unavailable, procedure not authorized.

Alt Set: INCHES

AMCHITKA I, ALASKA
AMCHITKA
LORAN RNAV 1 Rwy 25

MXY 9990

Apt Elev 228'



MISSED APPROACH: Climb to 1500', then climbing LEFT turn to 2500' direct W/P NAVIE and hold.

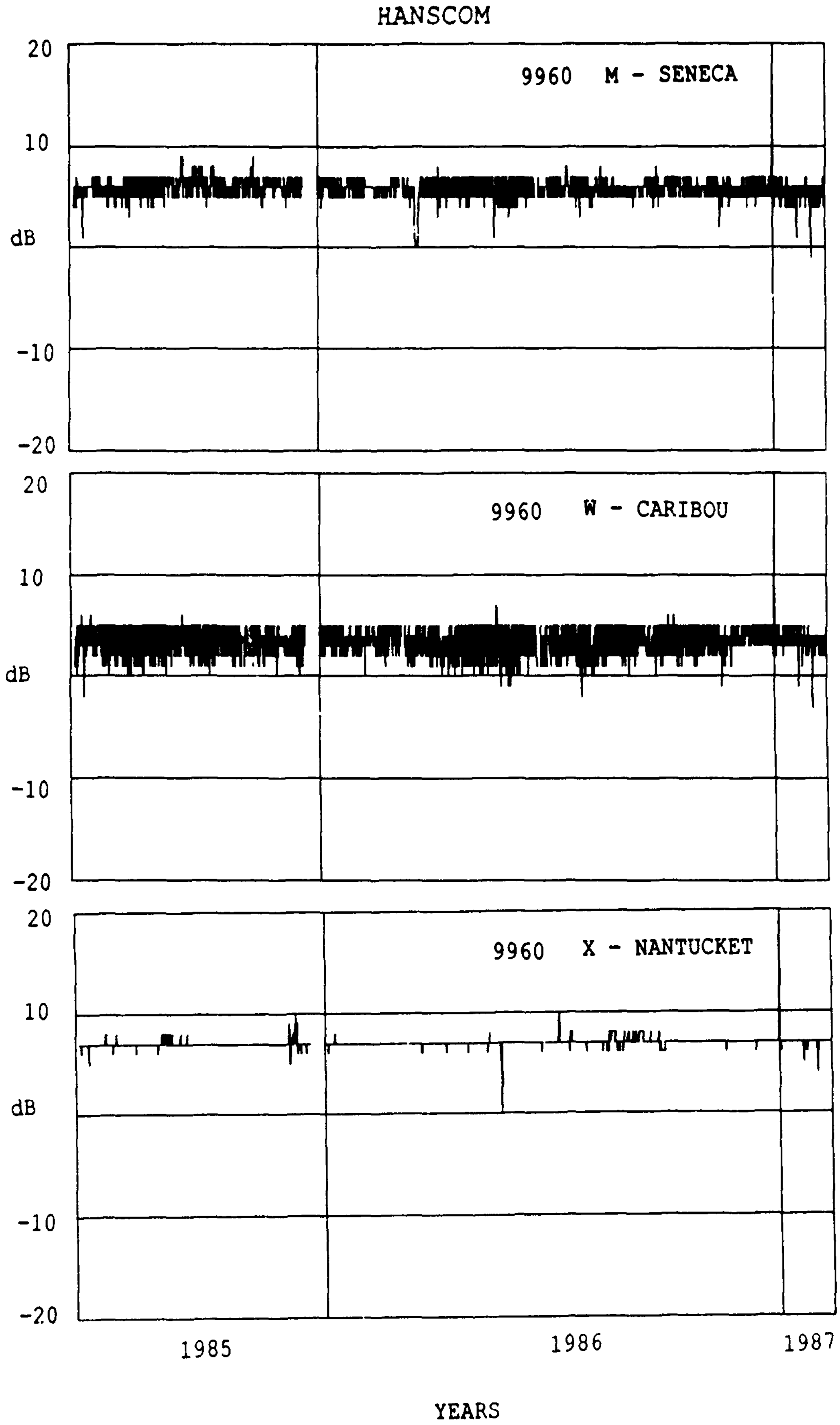
	STRAIGHT-IN LANDING RWY 25 MDA 600' (372') DAY	NIGHT		CIRCLE-TO-LAND DAY MDA	NIGHT
A	1	NA	A	640' (412') - 1	NA
B	1	NA	B	680' (452') - 1	NA
C	1	NA	C	680' (452') - 1 1/2	NA
D	1 1/4	NA	D	780' (552') - 2	NA

CHANGES: Printing sequence: reverse side NDB or NDB DME Rwy 7 cancelled

APPENDIX D

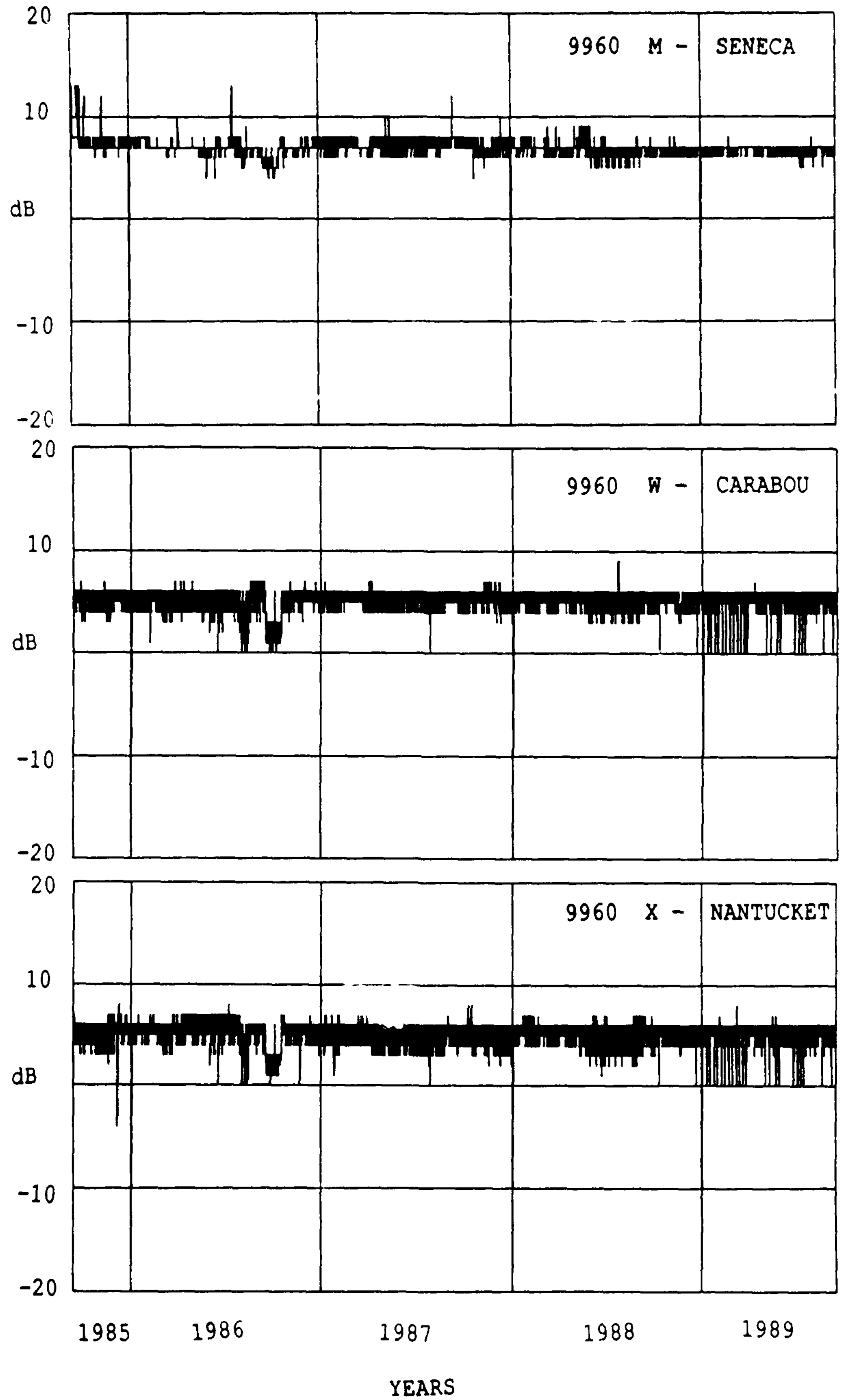
SIGNAL-TO-NOISE RATIO PLOTS

Signal-to-noise ratio plots are shown in the following fourteen pages, 12 of SNR plots, and 2 of minima (Lakefront, Orlando).



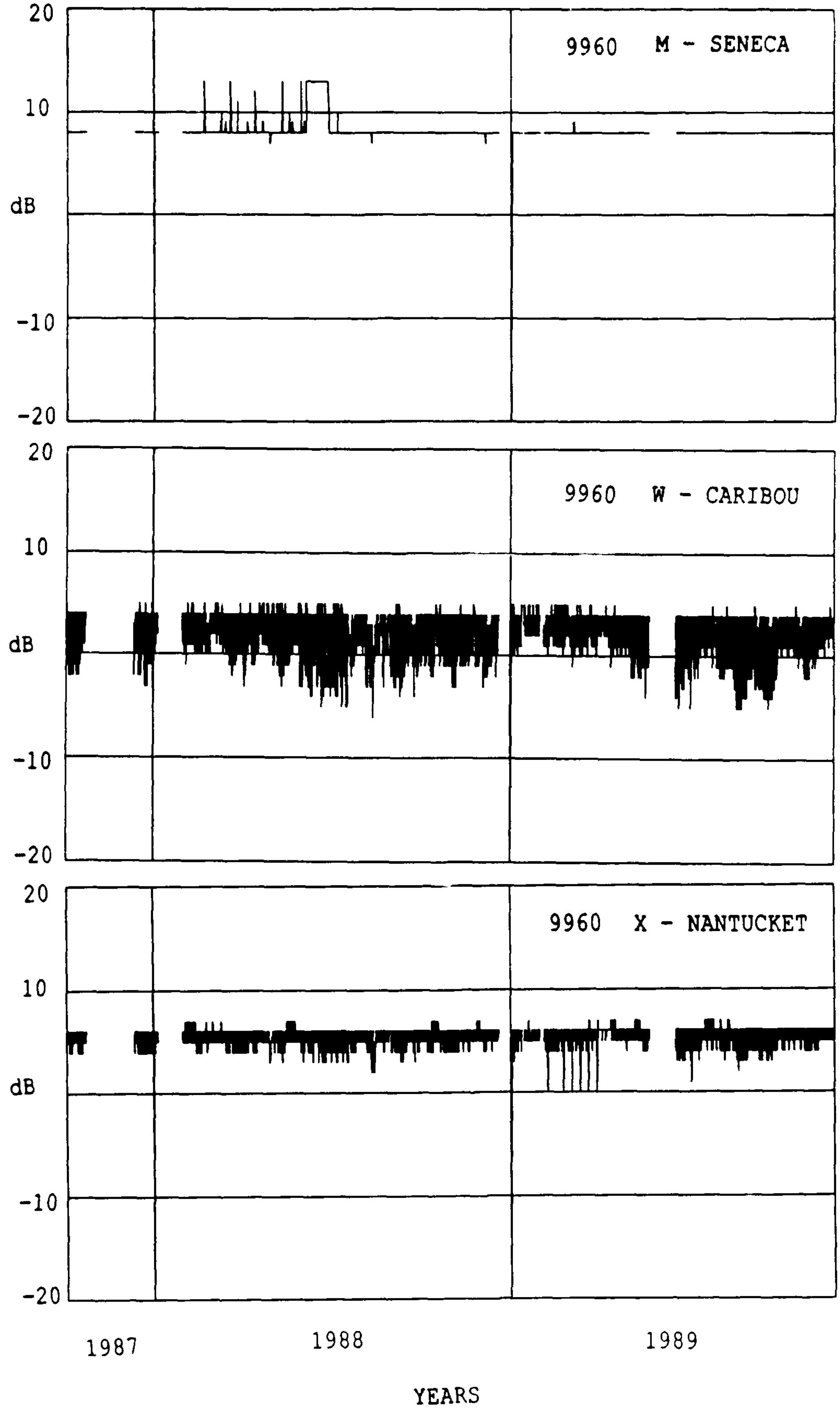
HANSCOM
9960 M - SENECA
9960 W - CARIBOU
9960 X - NANTUCKET
20
10
dB
-10
-20
1985
1986
1987
YEARS

BURLINGTON



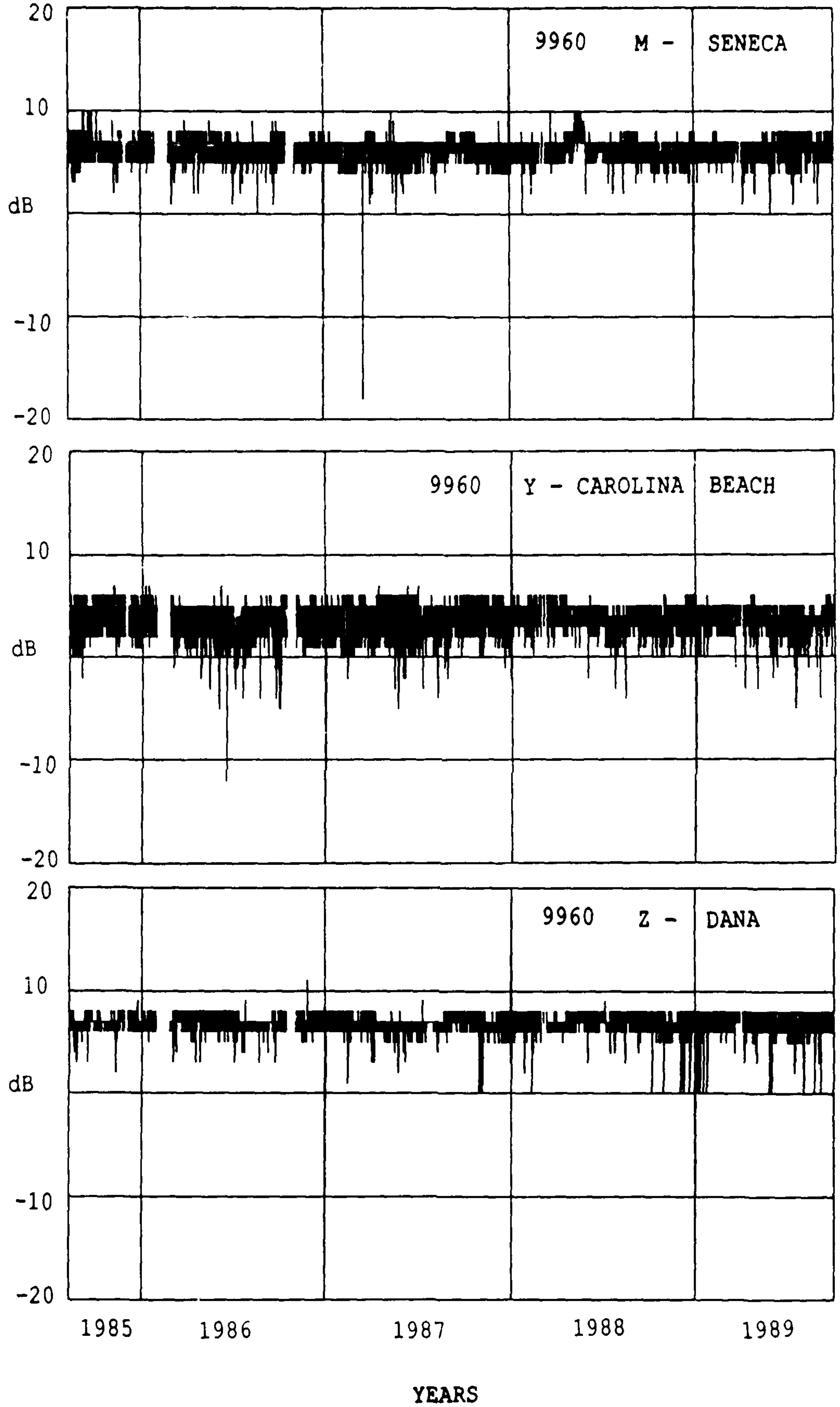
20
10
dB
-10
-20
9960 M - SENECA
20
10
dB
-10
-20
9960 W - CARABOU
20
10
dB
-10
-20
9960 X - NANTUCKET
1985
1986
1987
1988
1989
YEARS

UTICA



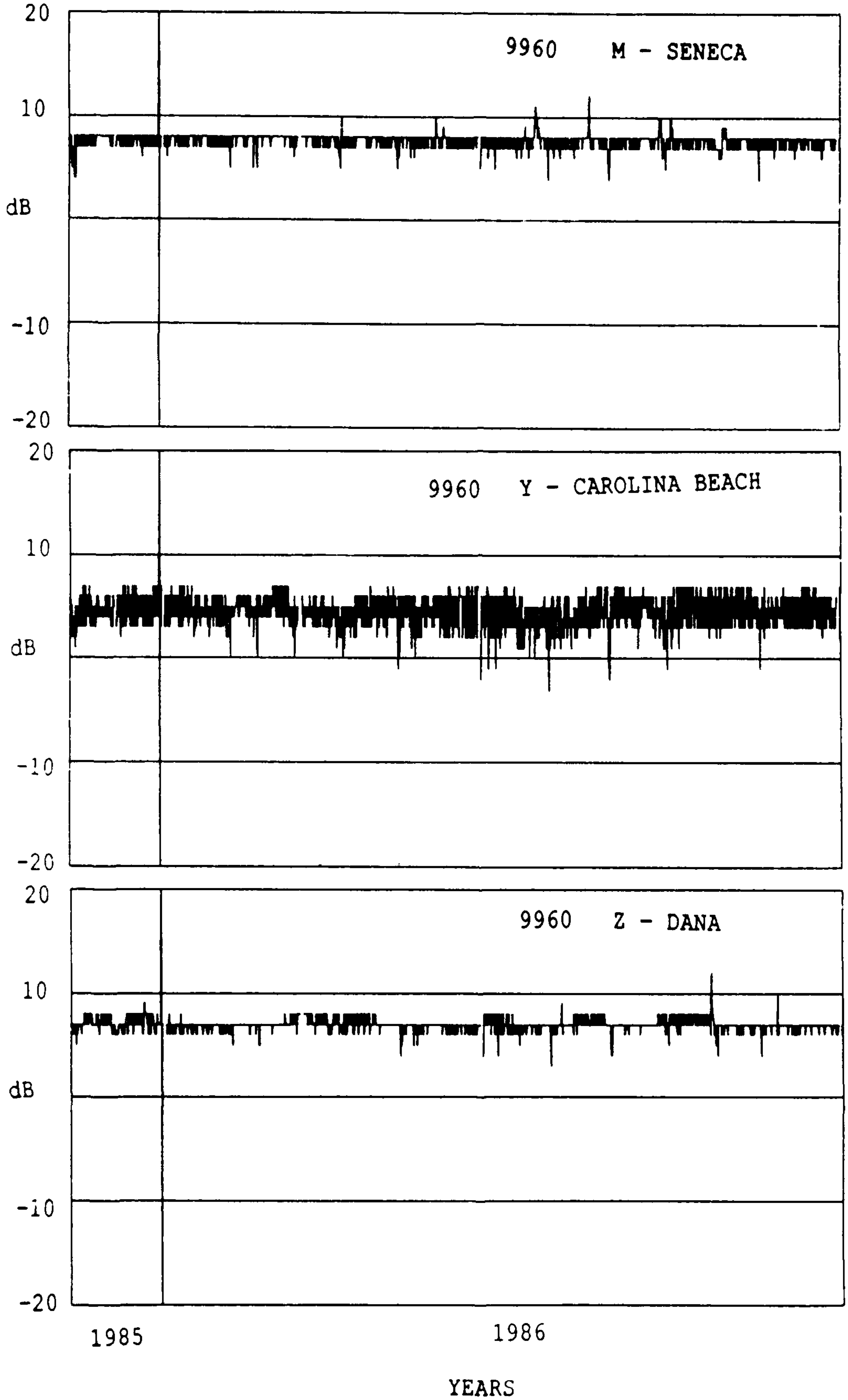
9960 M - SENECA
9960 W - CARIBOU
9960 X - NANTUCKET
20
10
dB
-10
-20
1987
1988
1989
YEARS

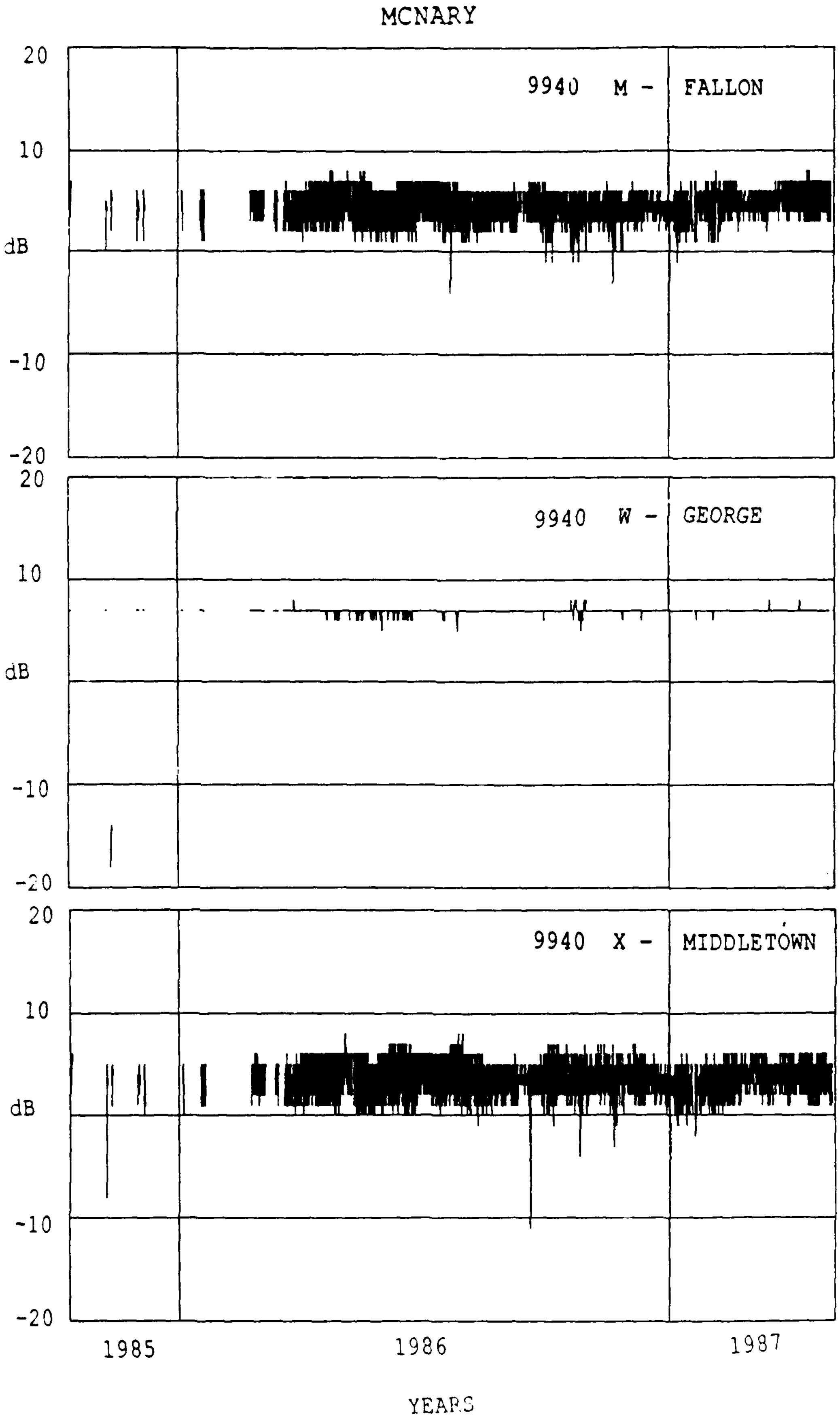
OHIO STATE



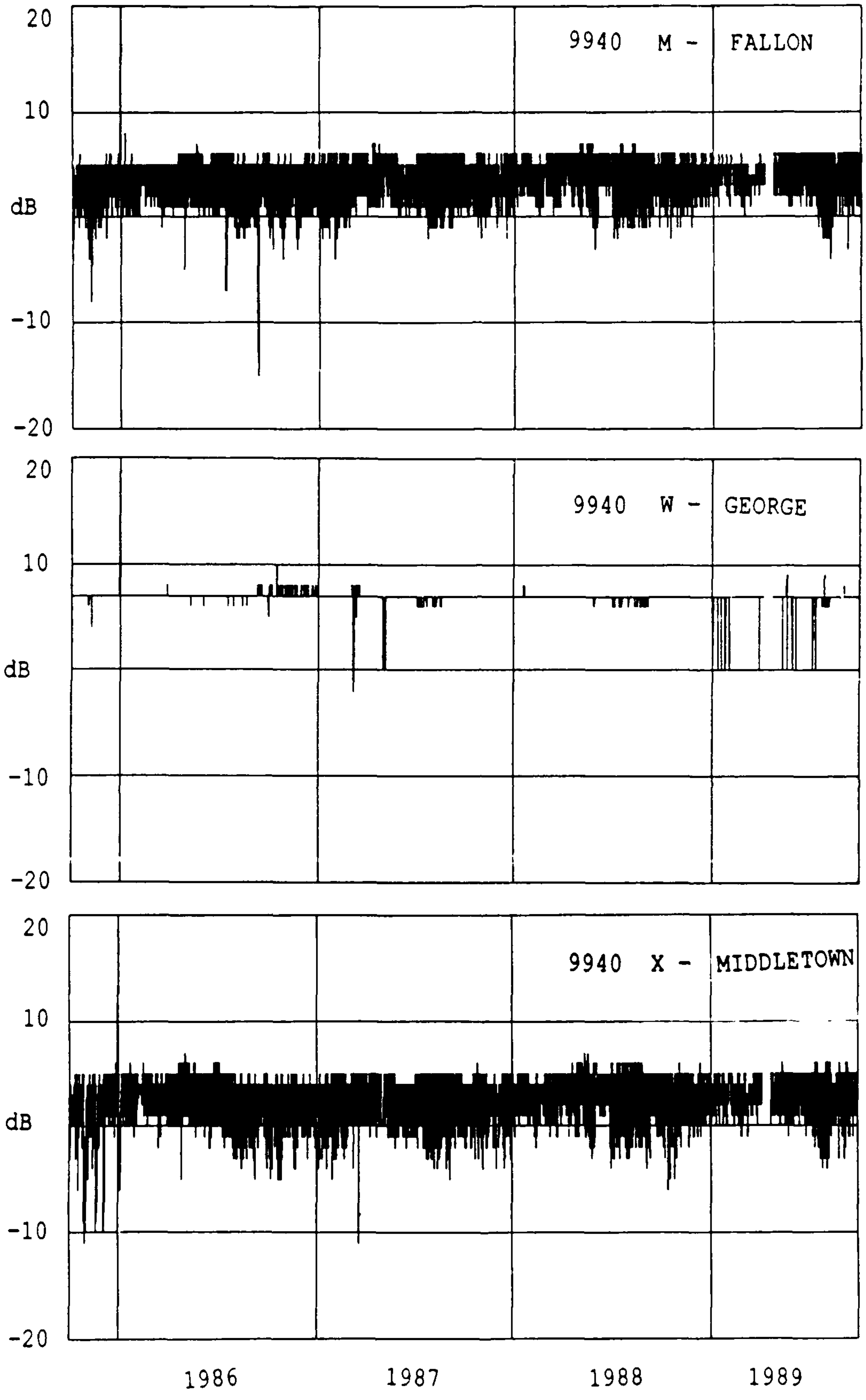
9960 M - SENECA
9960 Y - CAROLINA BEACH
9960 Z - DANA
20
10
-10
-20
dB
1985
1986
1987
1988
1989
YEARS

MANSFIELD


20
10
dB
-10
-20
9960 M - SENECA
20
10
dB
-10
-20
9960 Y - CAROLINA BEACH
20
10
dB
-10
-20
9960 Z - DANA
1985
1986
YEARS

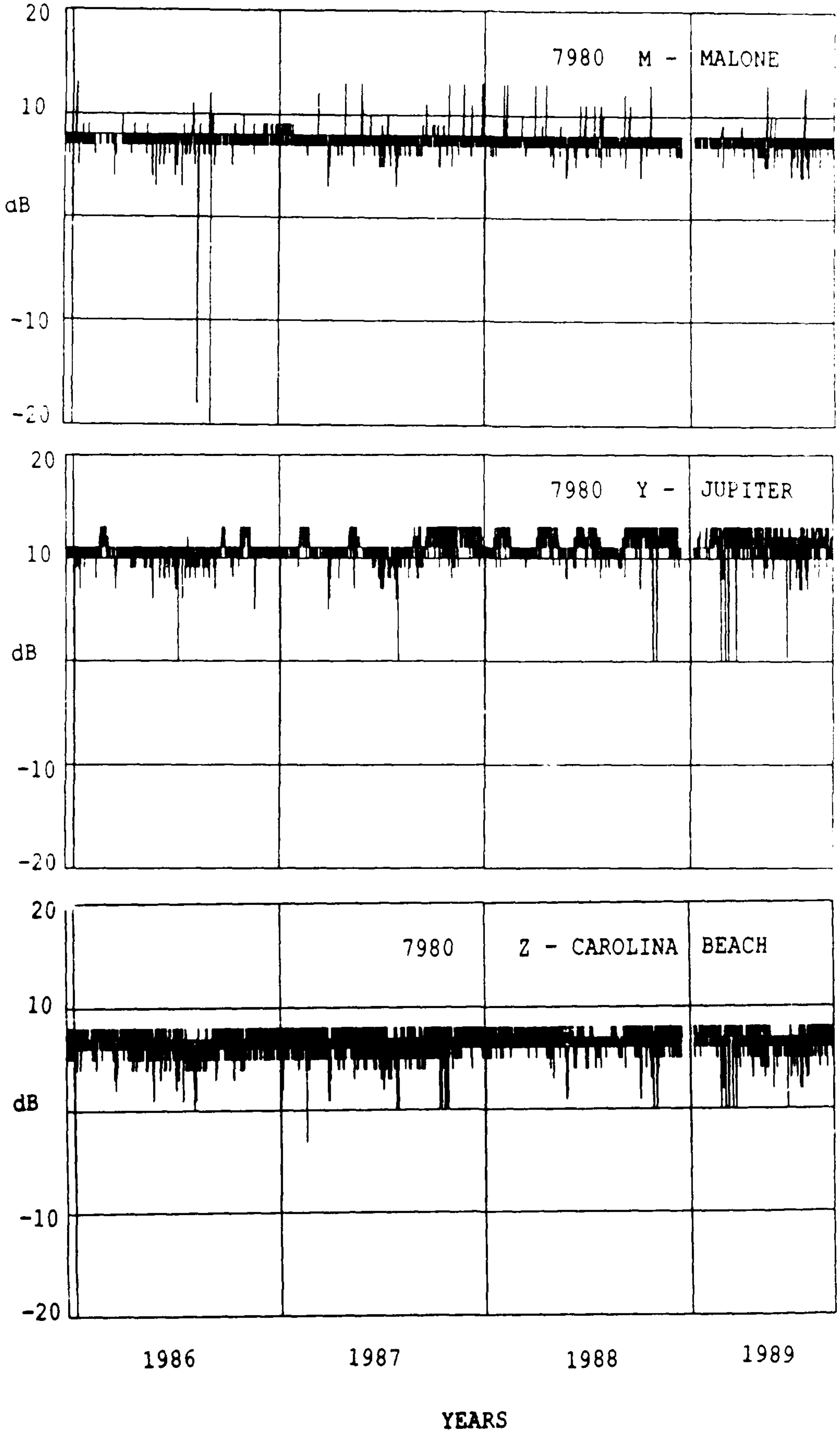

MCNARY
20
10
dB
-10
-20
9940 M - FALLON
9940 W - GEORGE
9940 X - MIDDLETOWN
1985
1986
1987
YEARS

PORTLAND



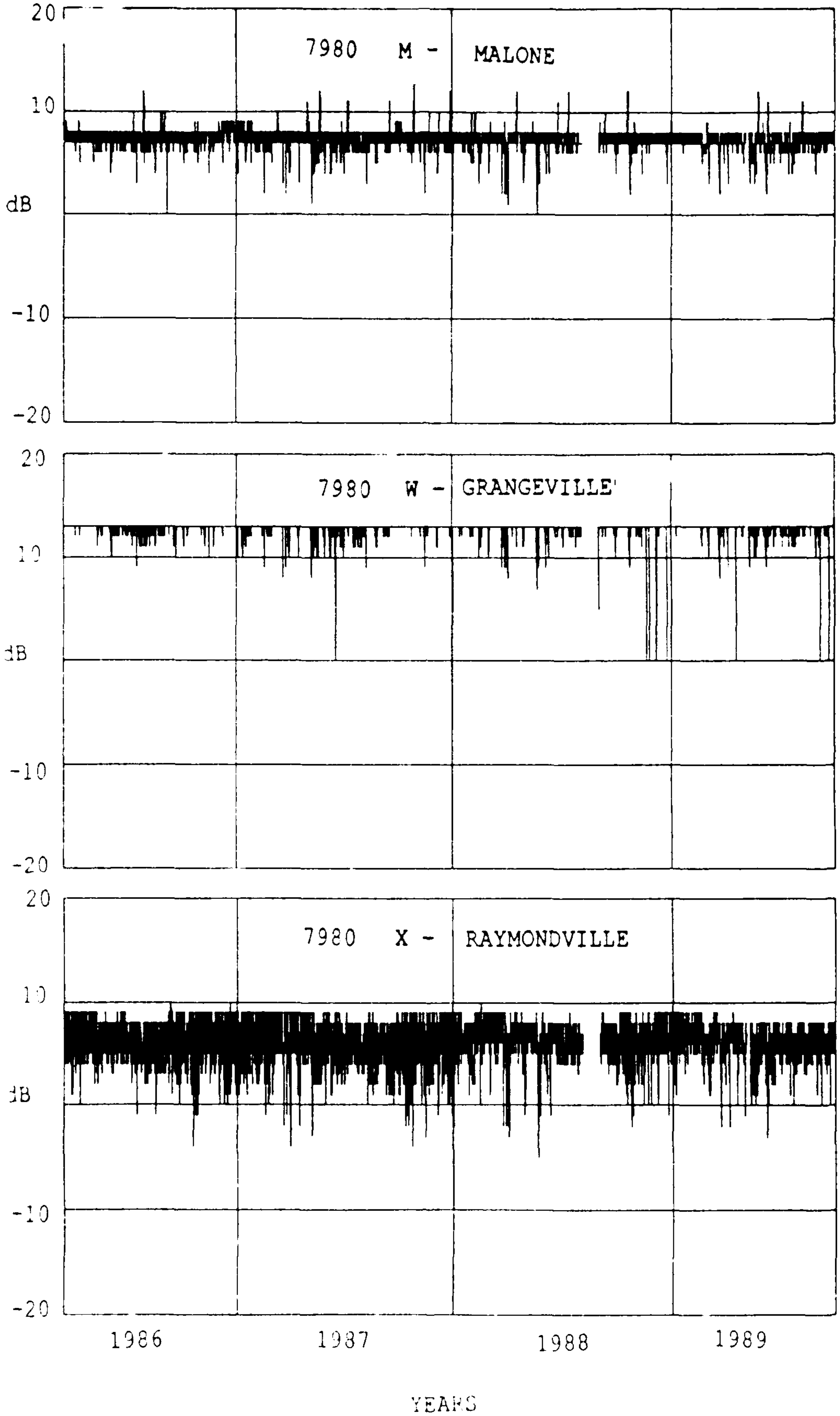
YEARS

ORLANDO



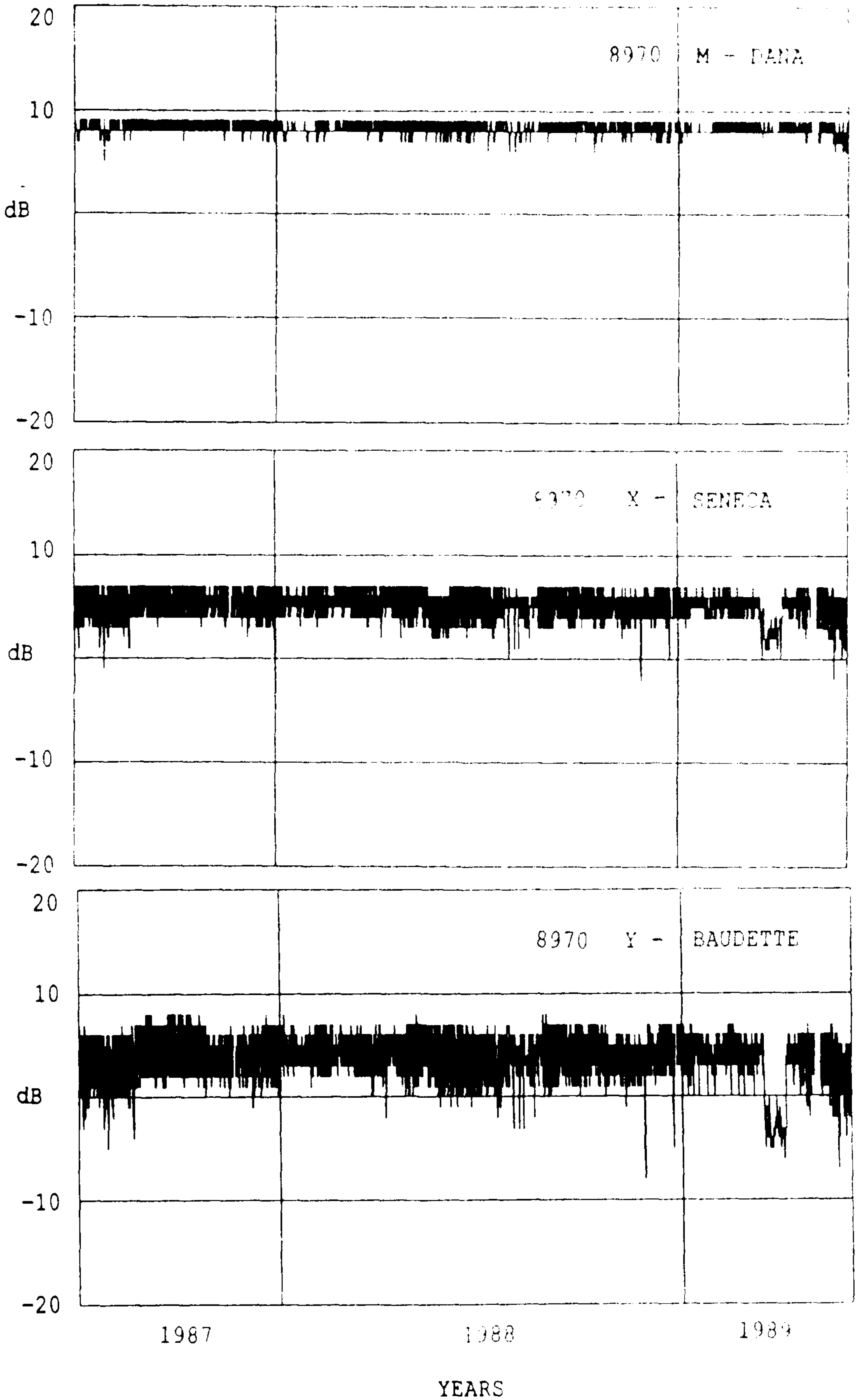
7980 M - MALONE
7980 Y - JUPITER
7980 Z - CAROLINA BEACH
20
10
-10
-20
dB
1986
1987
1988
1989
YEARS

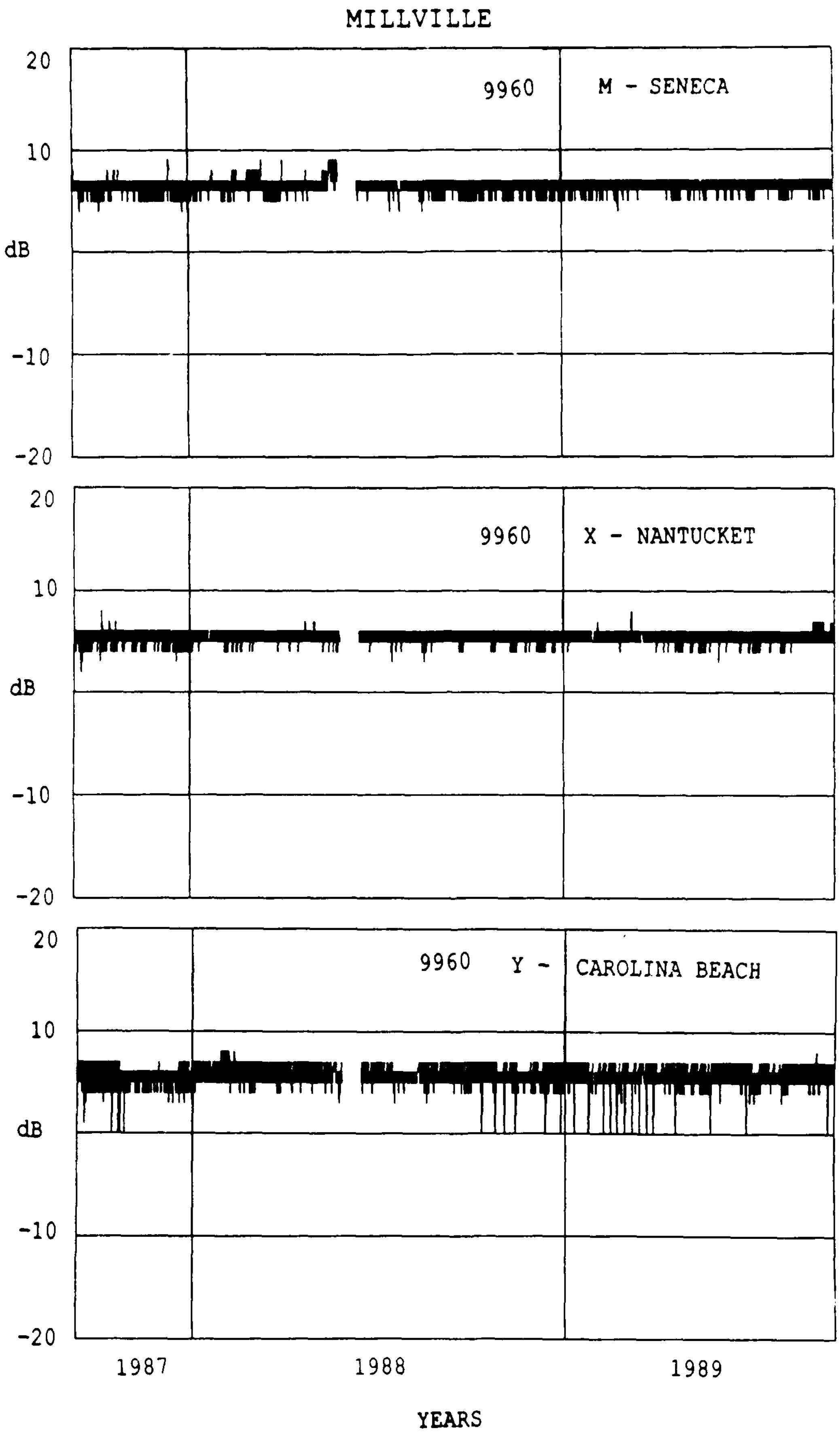
LAKEFRONT



7980 M - MALONE
7980 W - GRANGEVILLE
7980 X - RAYMONDVILLE
20
10
dB
-10
-20
1986
1987
1988
1989
YEARS

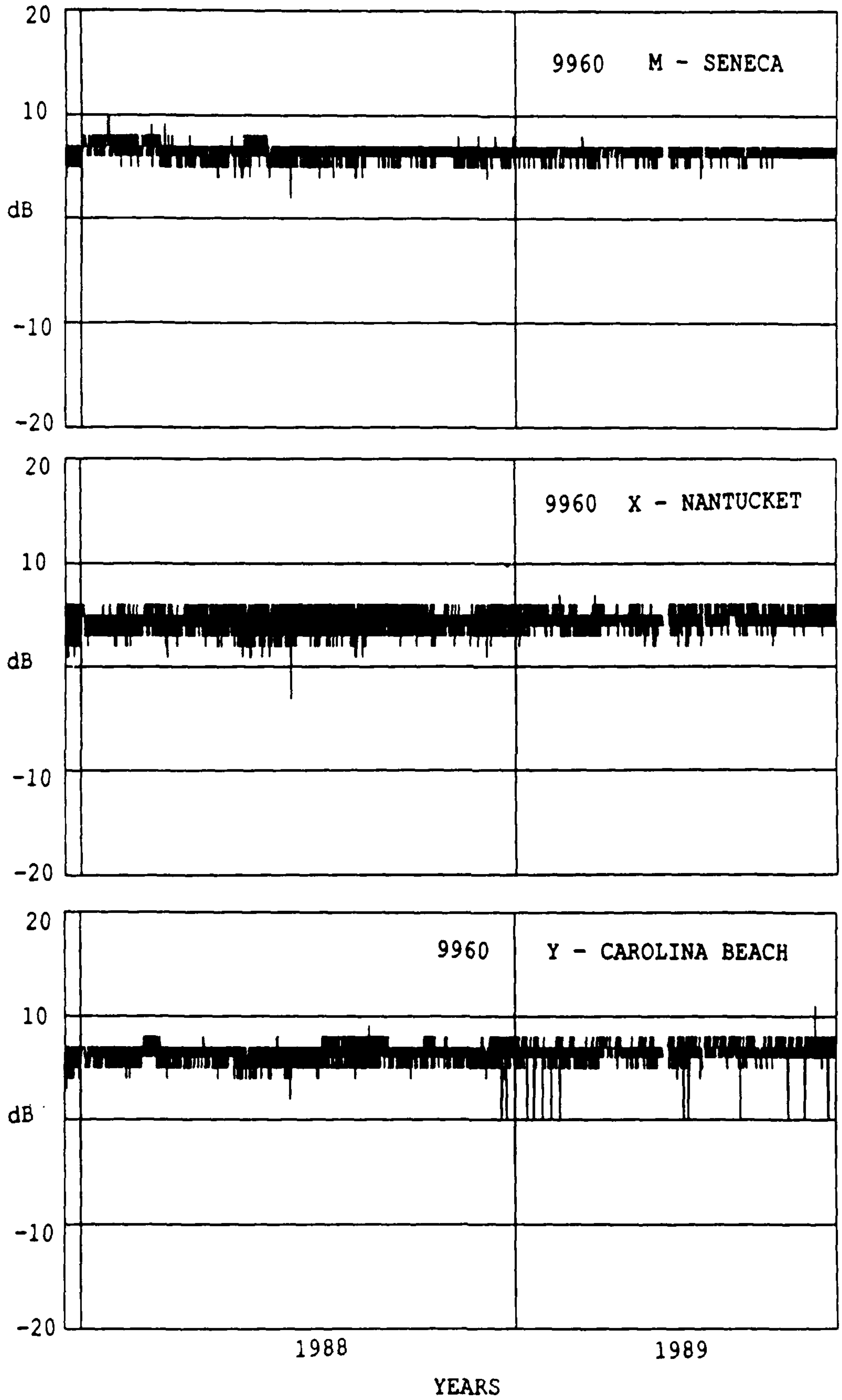
SOUTHBEND


8970 M - DANA
X - SENECA
8970 Y - BAUDETTE
20
10
dB
-10
-20
1987
1988
1989
YEARS



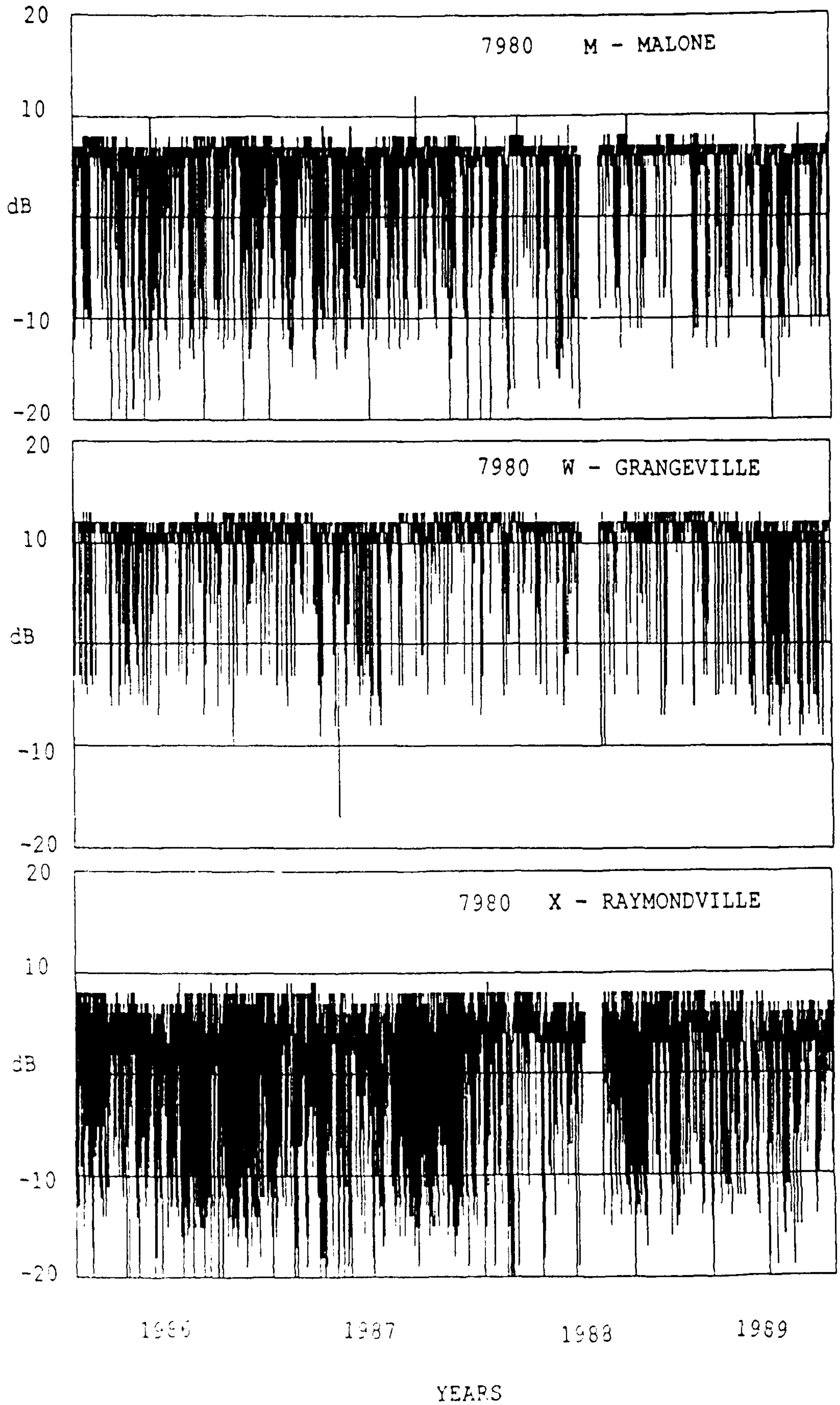
MILLVILLE
9960
M - SENECA
9960
X - NANTUCKET
9960
Y - CAROLINA BEACH
20
10
dB
-10
-20
1987
1988
1989
YEARS

MANASSAS



9960 M - SENECA
9960 X - NANTUCKET
9960 Y - CAROLINA BEACH
20
10
dB
-10
-20
1988
1989
YEARS

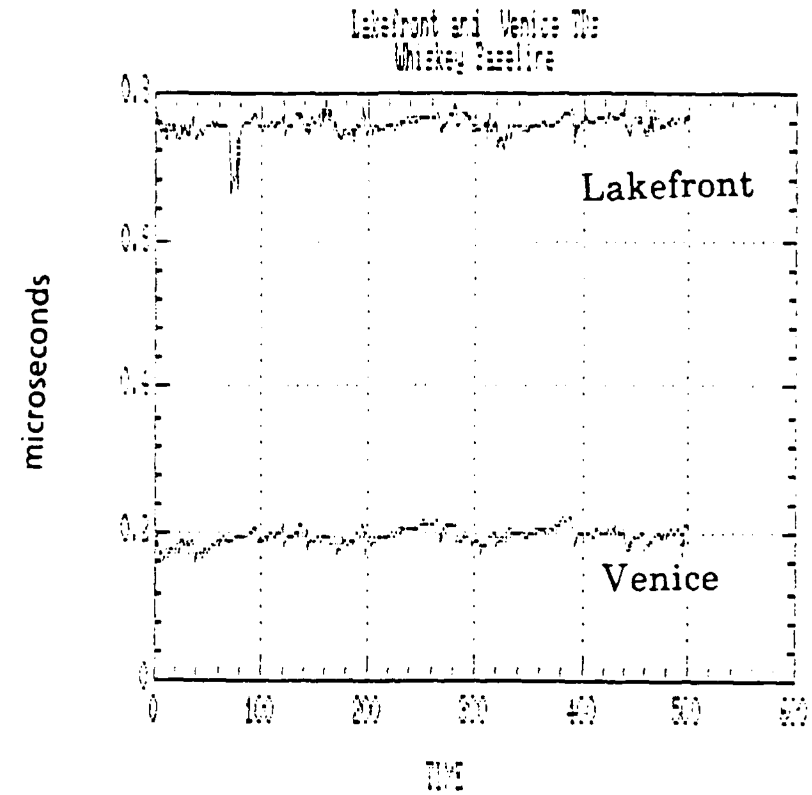
LAKEFRONT

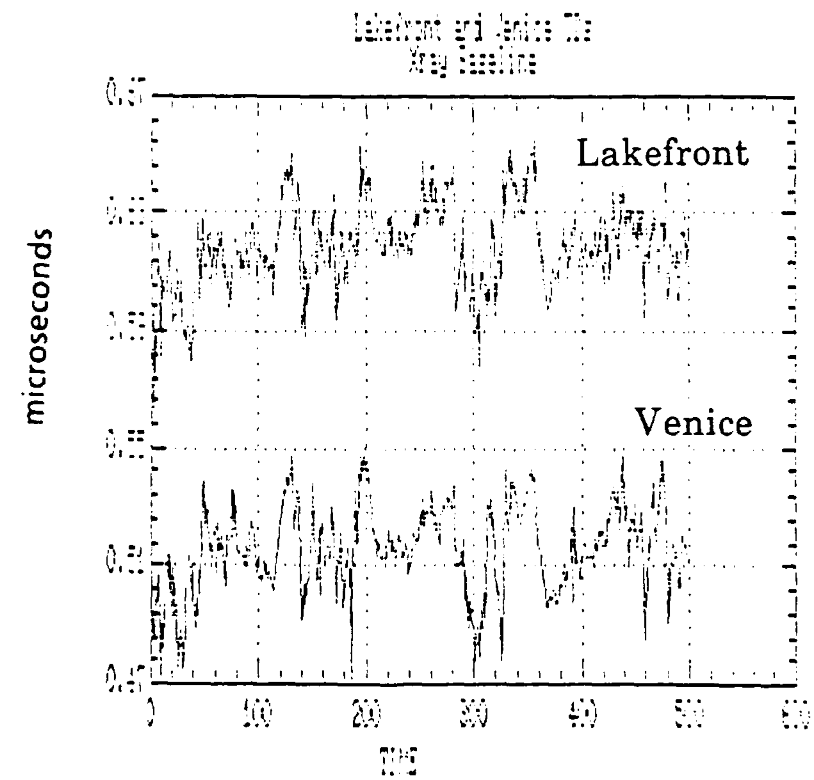

7980 M - MALONE
7980 W - GRANGEVILLE
7980 X - RAYMONDVILLE
20
10
dB
-10
-20
1987
1988
1989
YEARS

APPENDIX E

TIME DIFFERENCE PLOTS

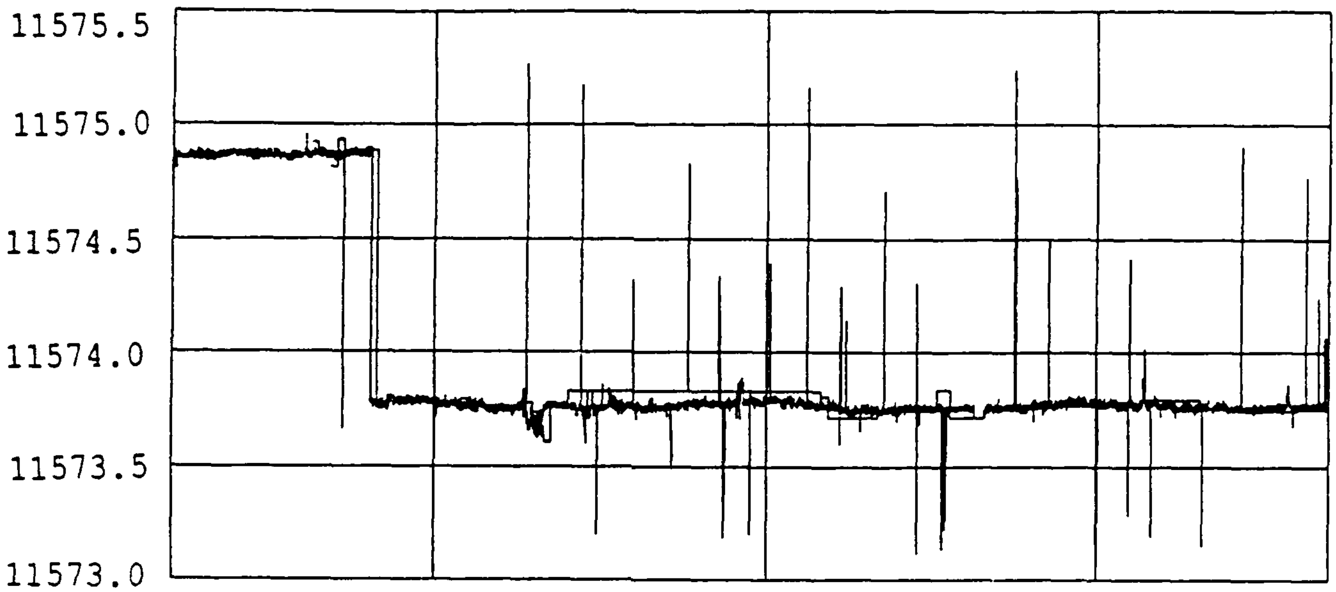
Loran EIP TD plots are given on the following 13 pages.


Lakefront
Venice
microseconds
0
100
200
300
400
500
600

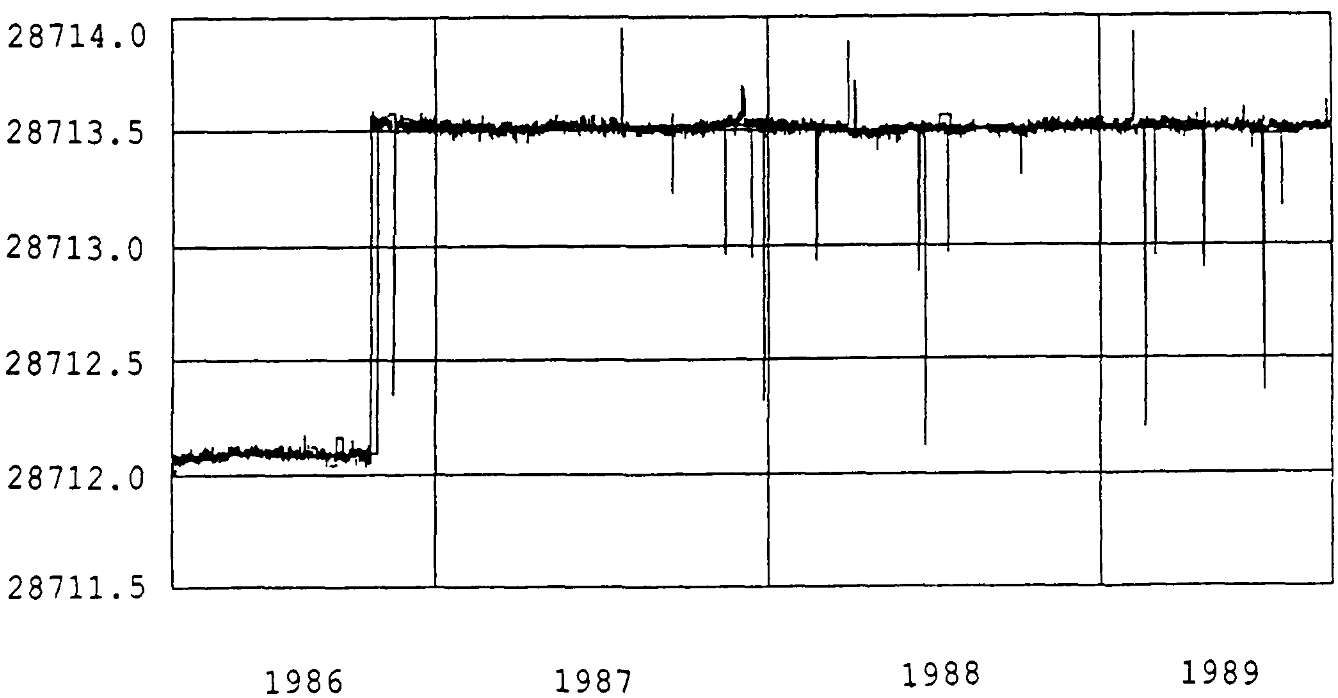

Lakefront
Venice
microseconds
0
100
200
300
400
500
600

LAKEFRONT'S FOUR HOUR AVERAGES

WHISKEY BASELINE

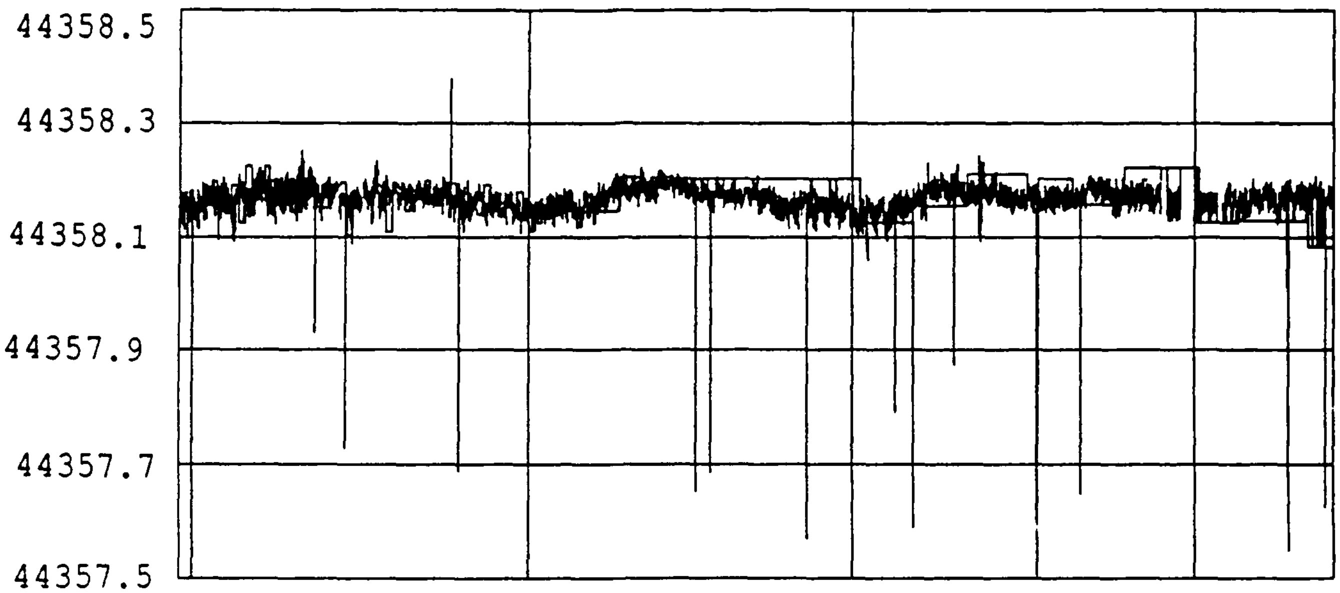


XRAY BASELINE

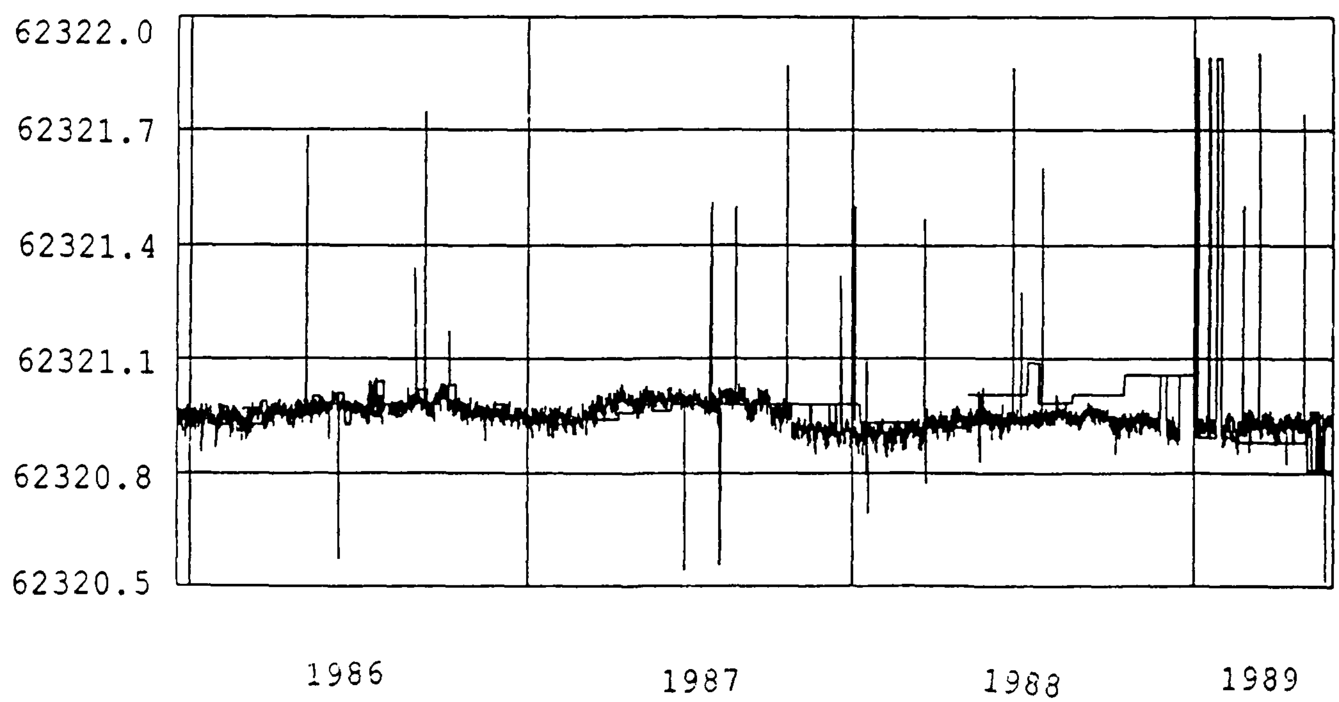


ORLANDO'S FOUR HOUR AVERAGES

YANKEE BASELINE

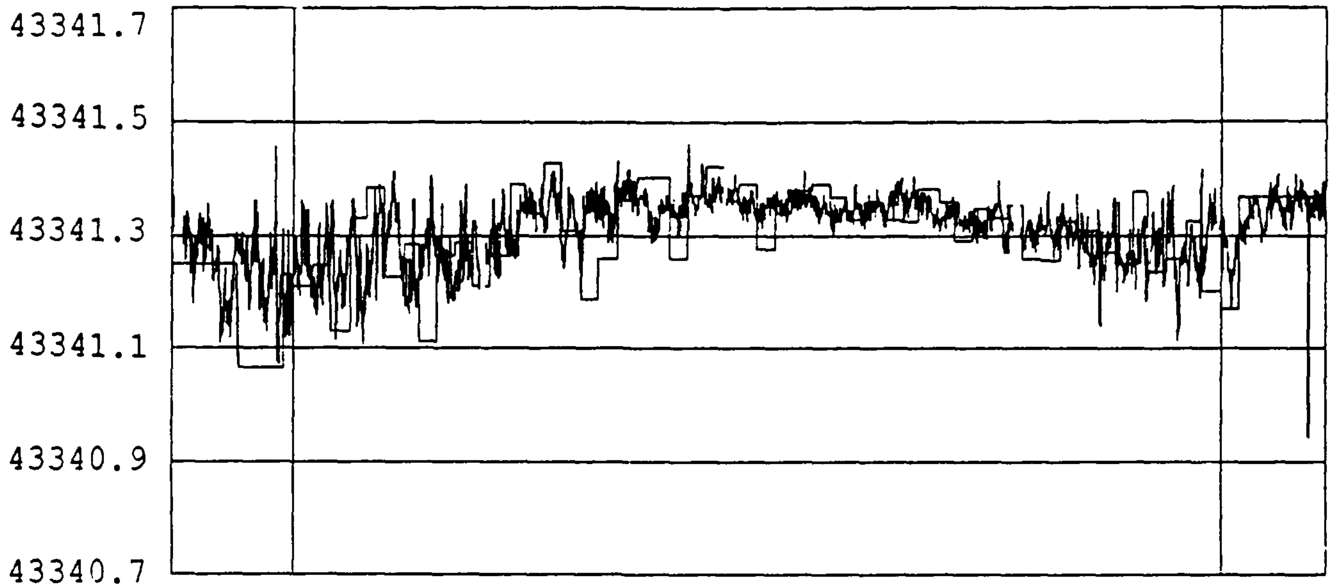


ZULU BASELINE

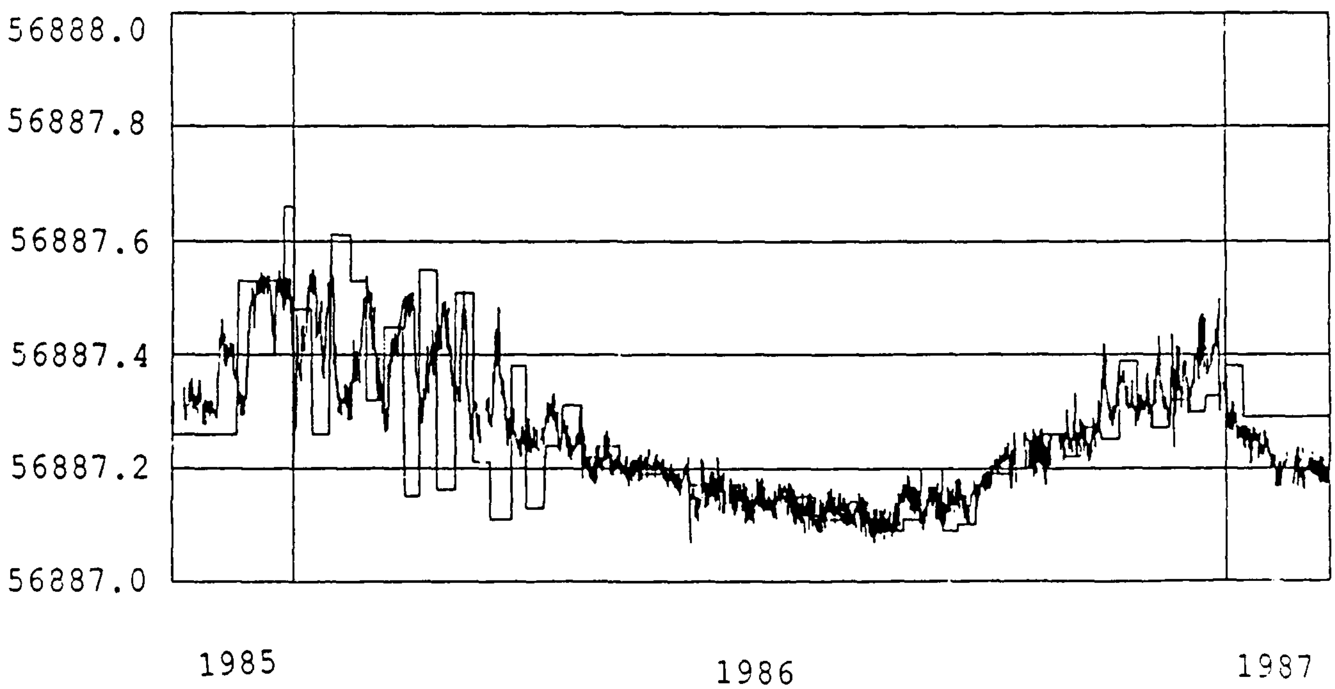


MANSFIELD'S FOUR HOUR AVERAGES

YANKEE BASELINE

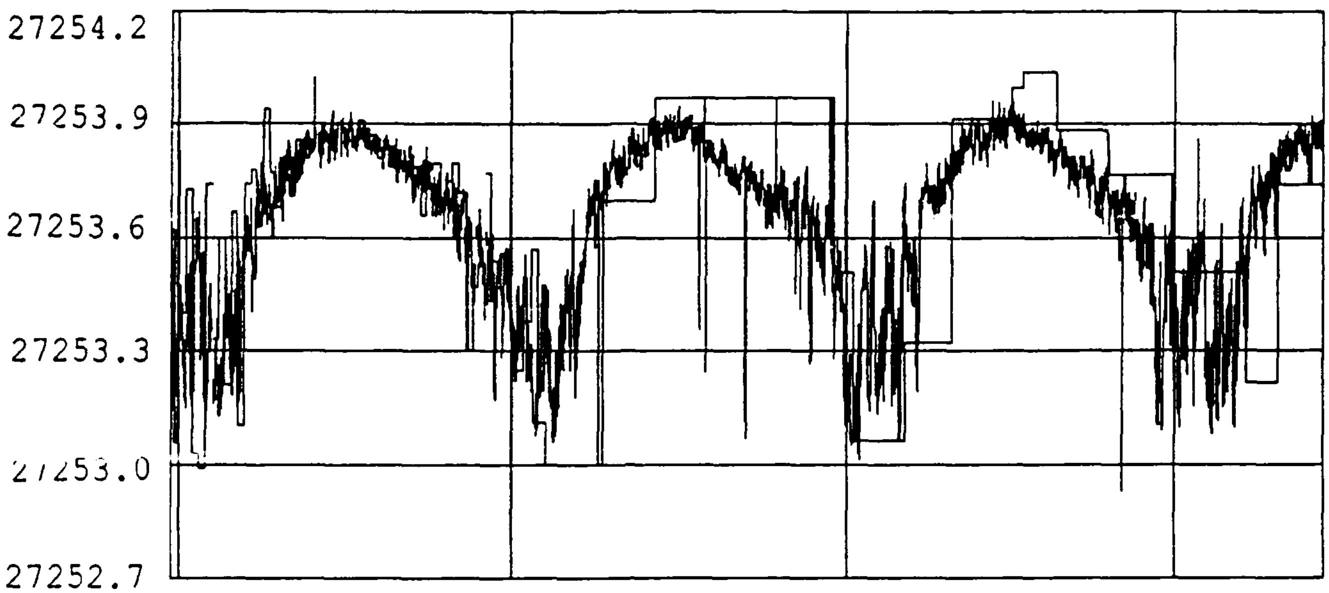


ZULU BASELINE

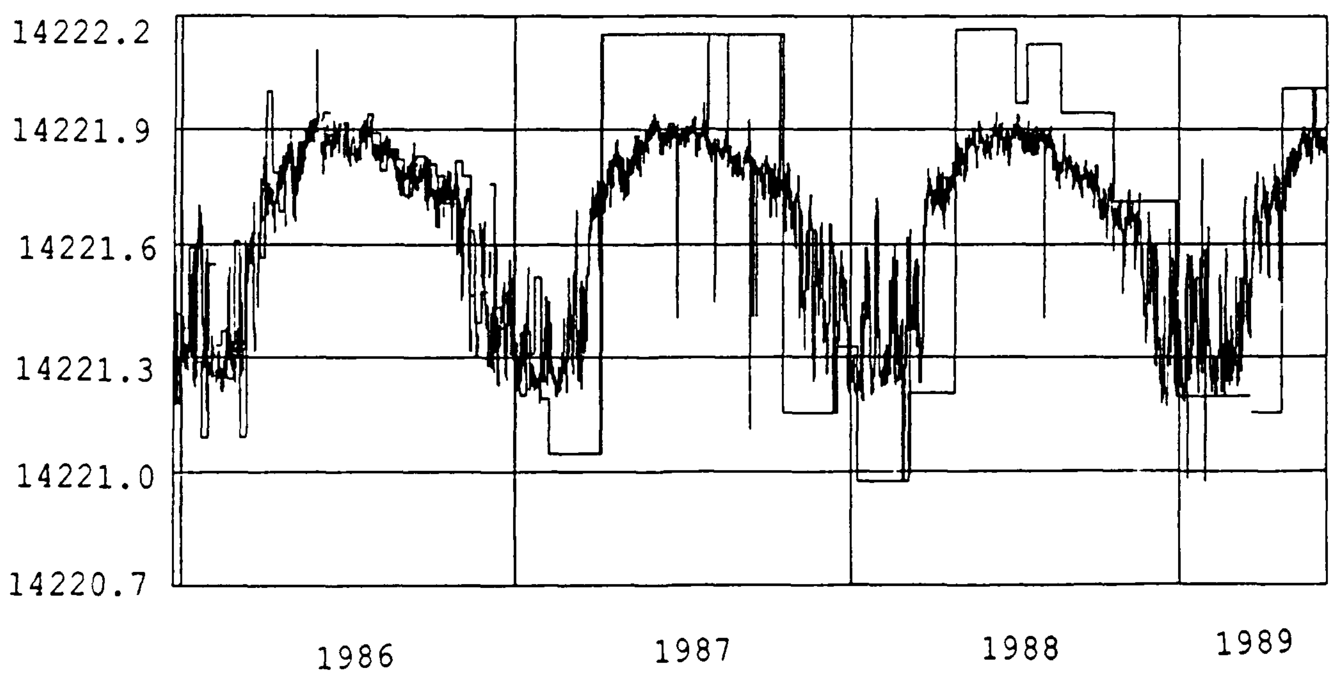


BURLINGTON'S FOUR HOUR AVERAGES

XRAY BASELINE

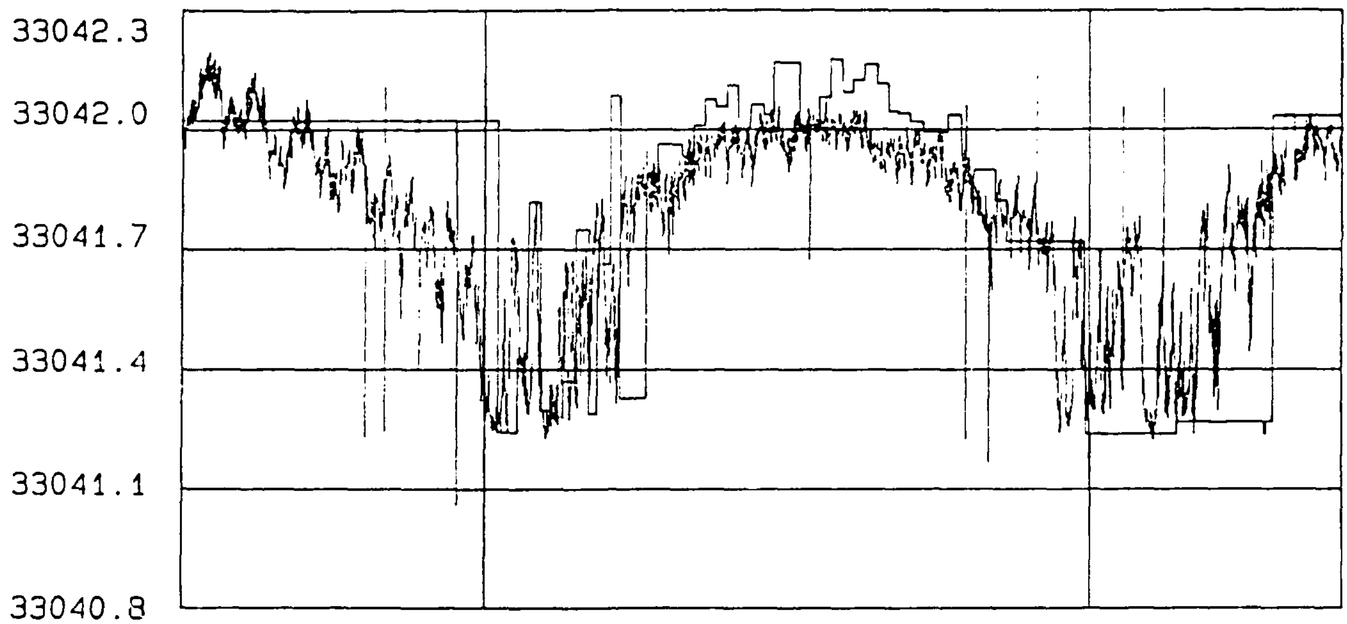


WHISKEY BASELINE

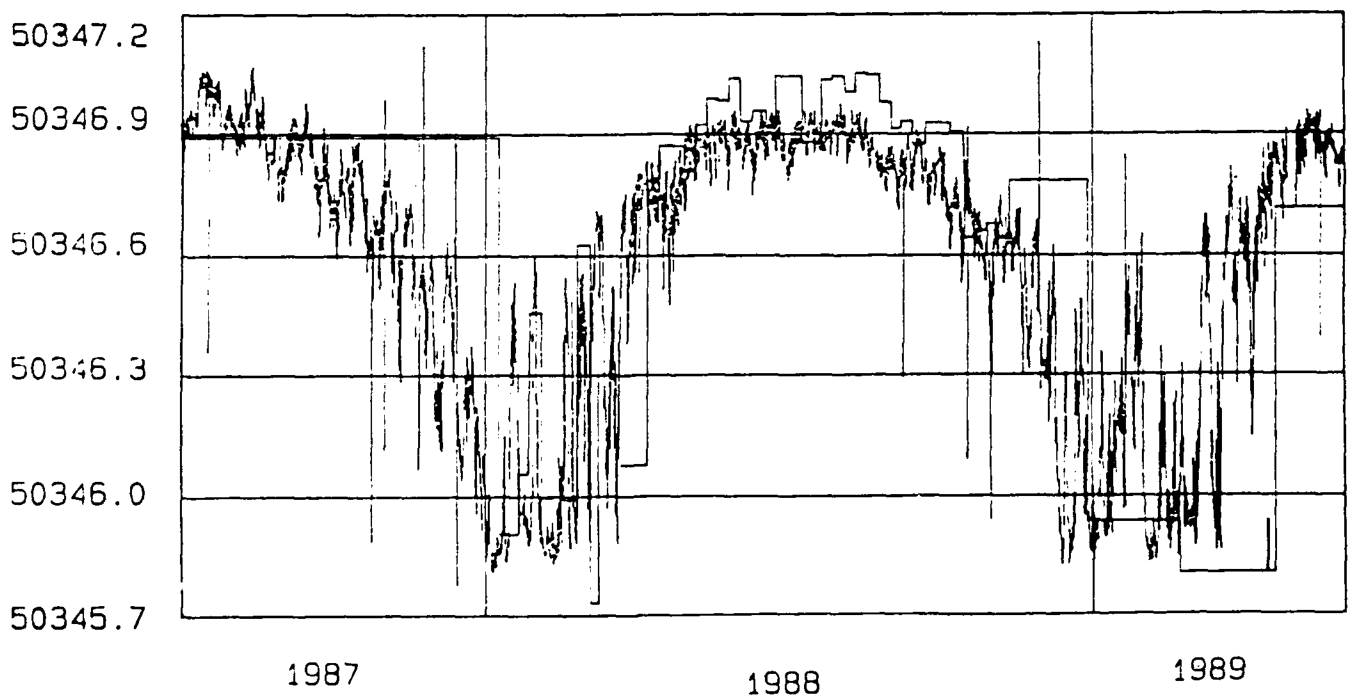


SOUTHBEND'S FOUR HOUR AVERAGES

XRAY BASELINE - 8970

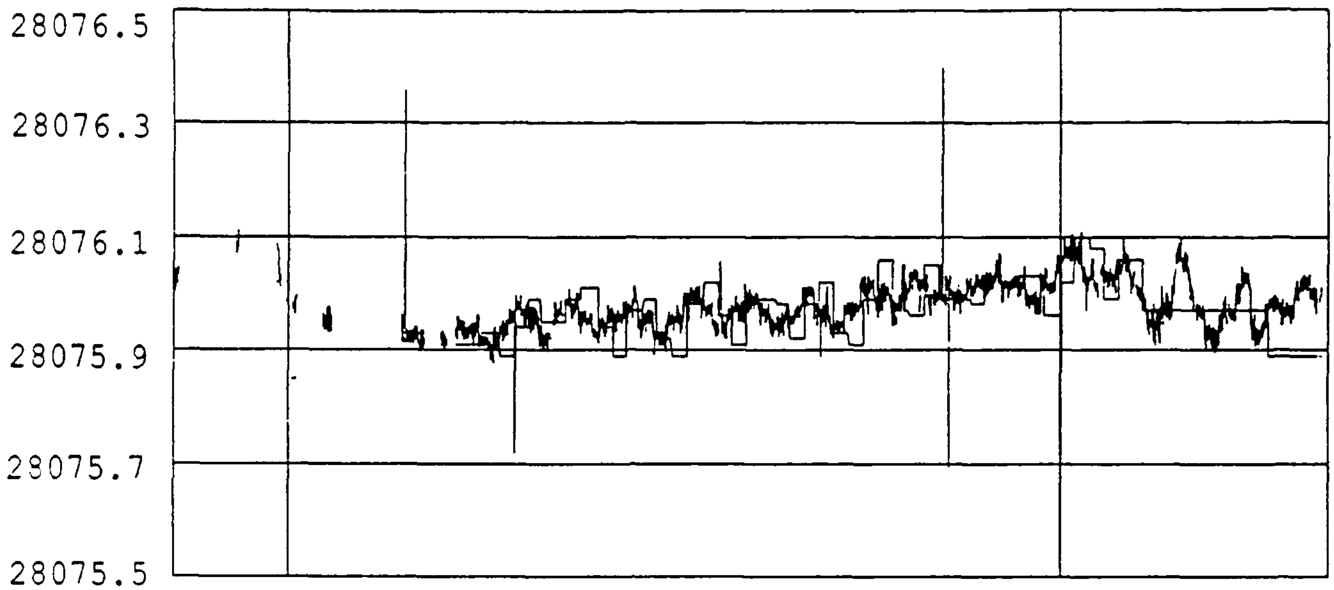


YANKEE BASELINE - 8970

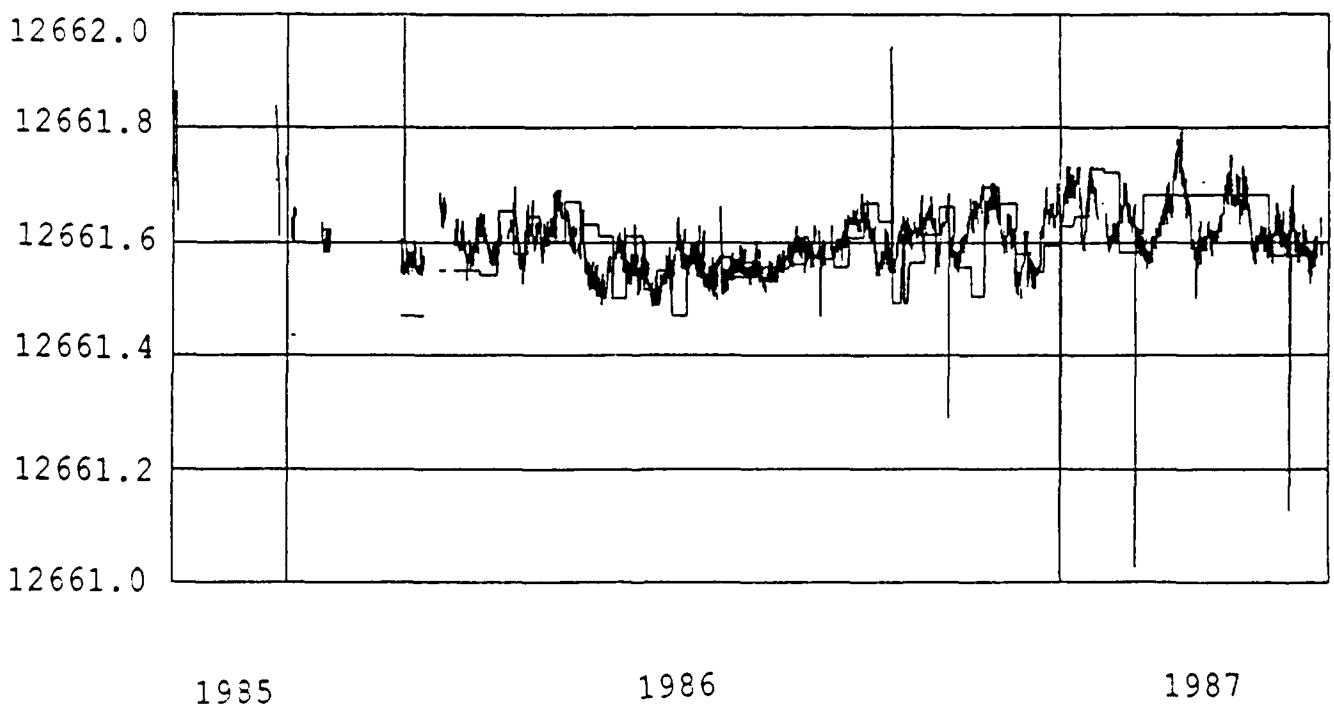


MCNARY'S FOUR HOUR AVERAGES

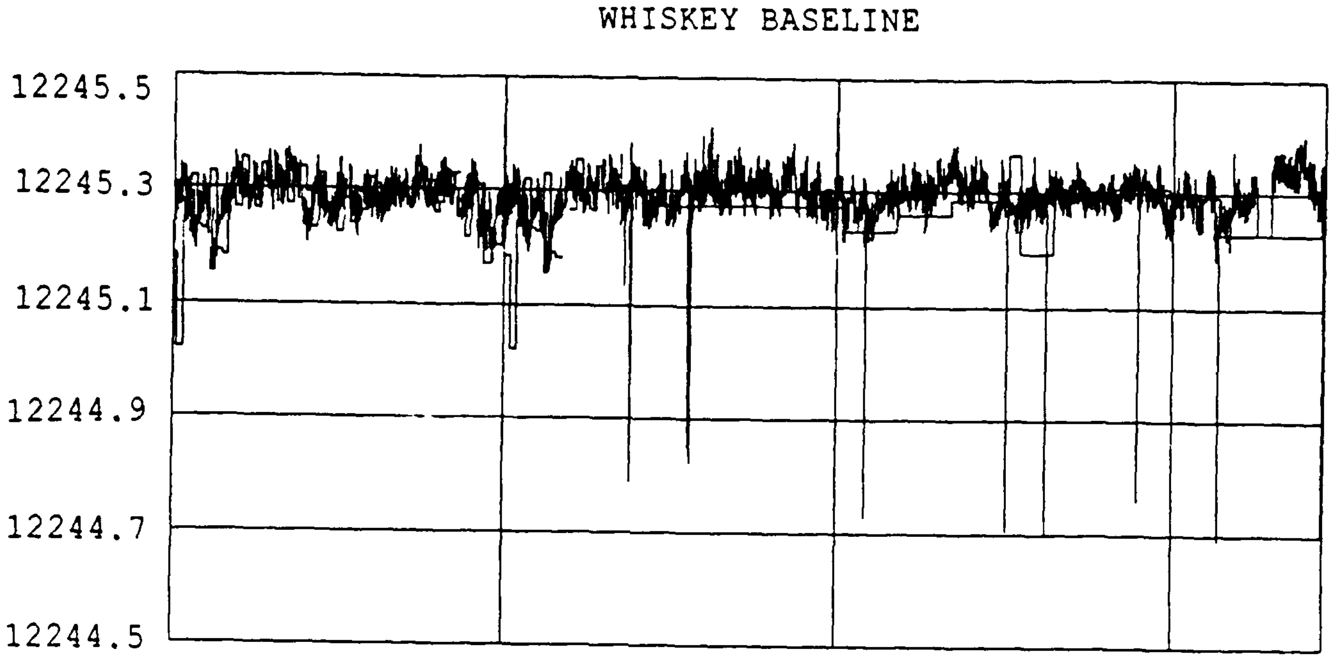
XRAY BASELINE

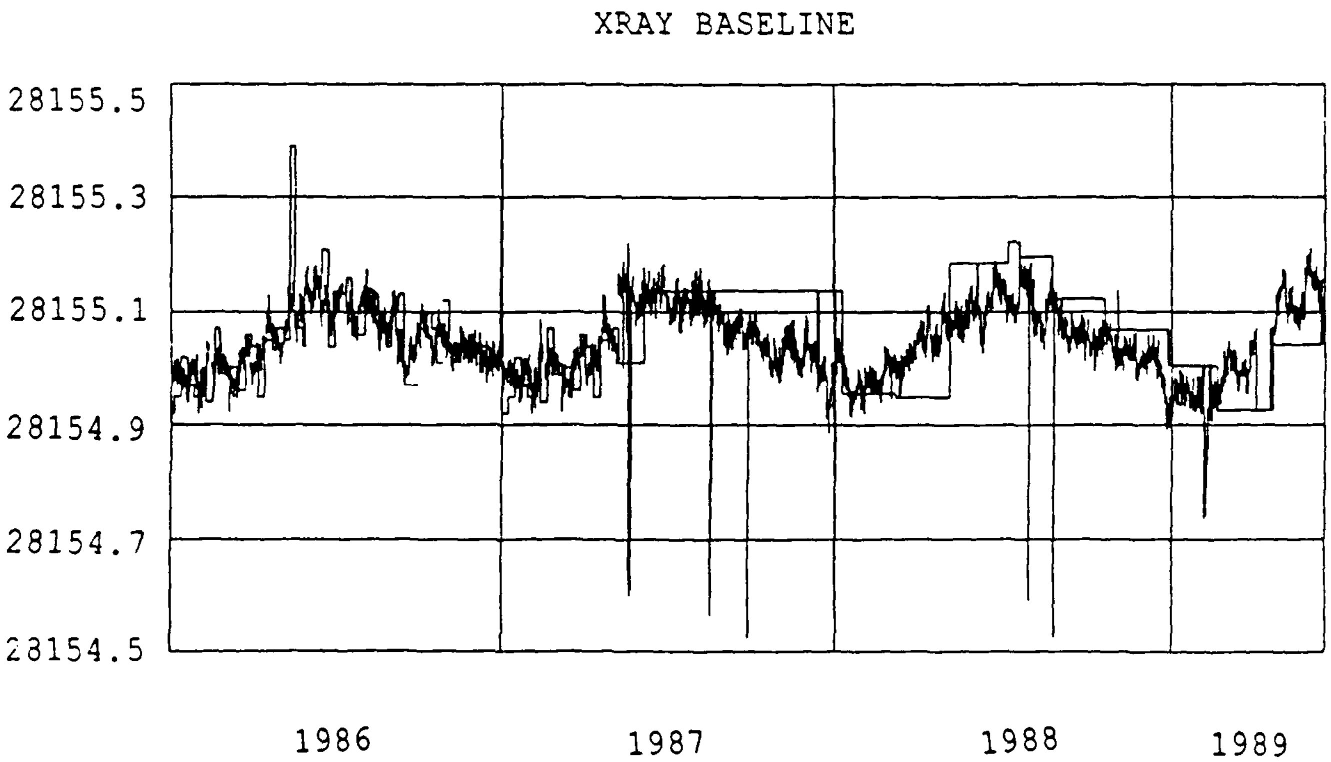


YANKEE BASELINE



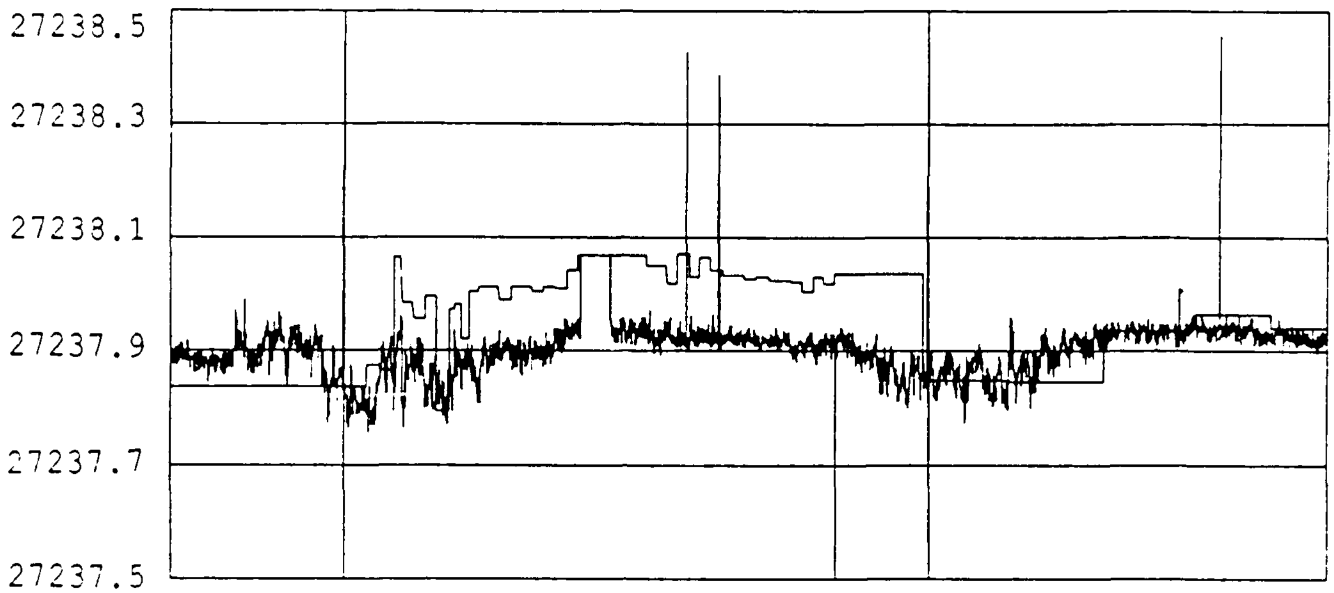
PORTLAND'S FOUR HOUR AVERAGES



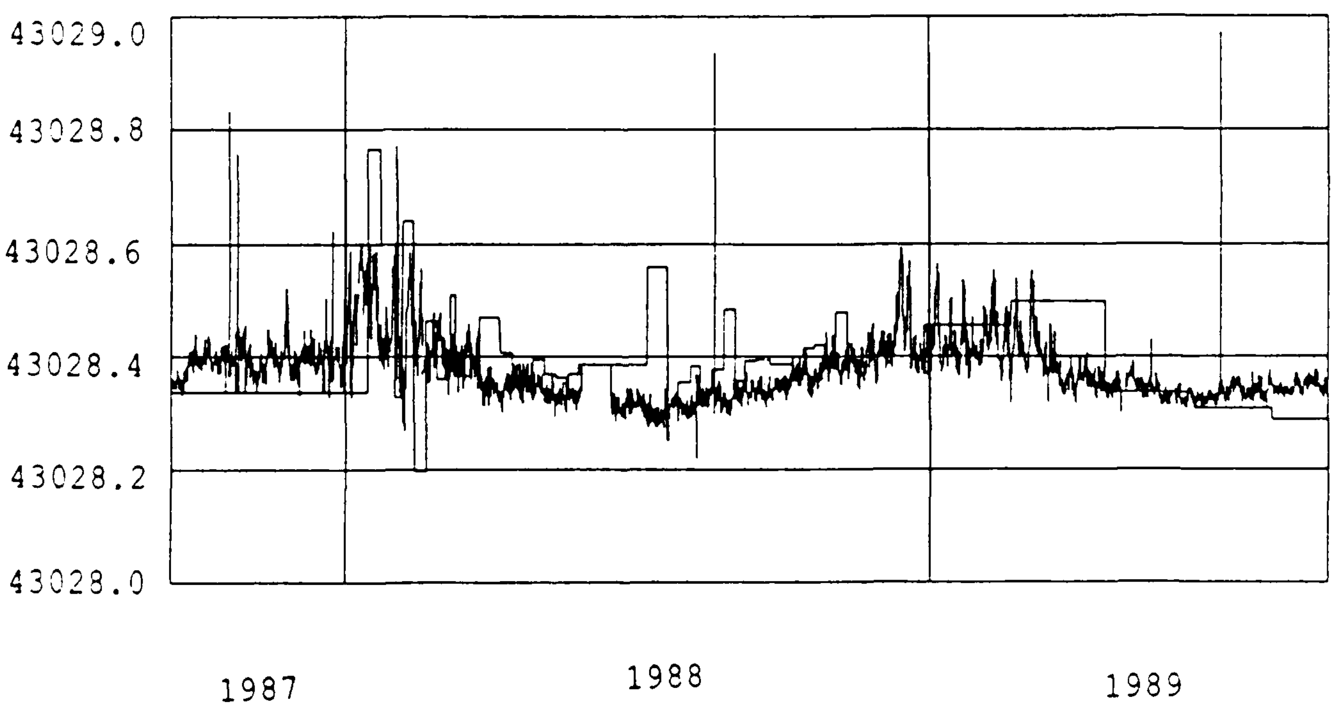


MILLVILLE'S FOUR HOUR AVERAGES

XRAY BASELINE

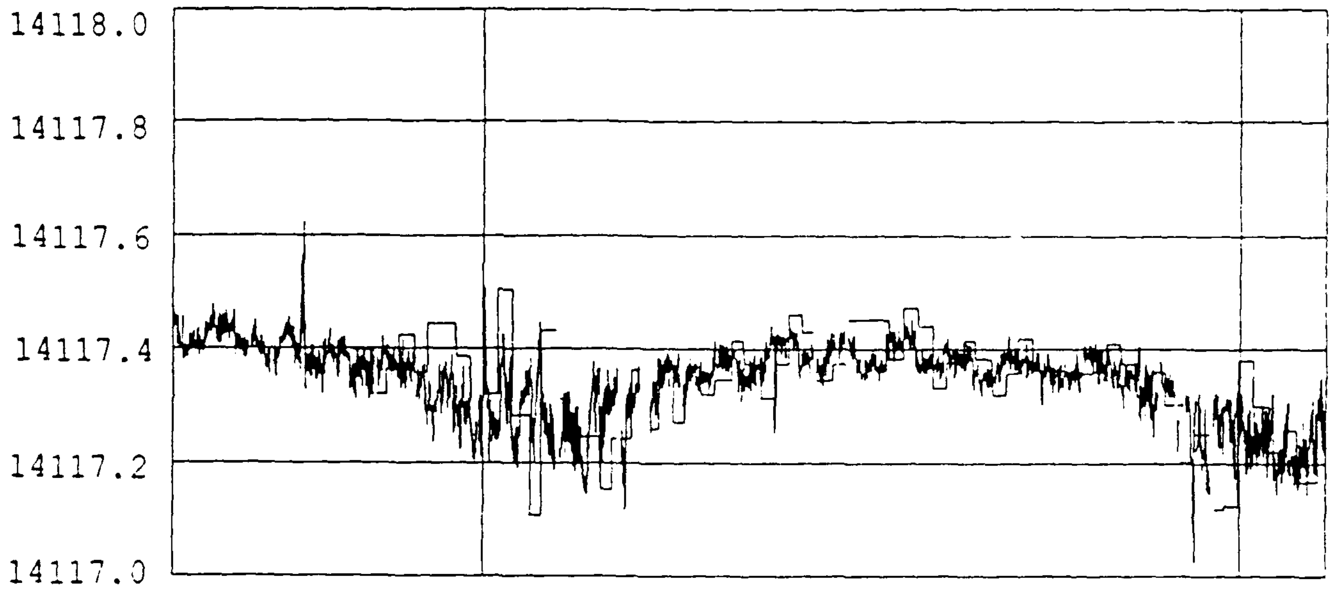


YANKEE BASELINE

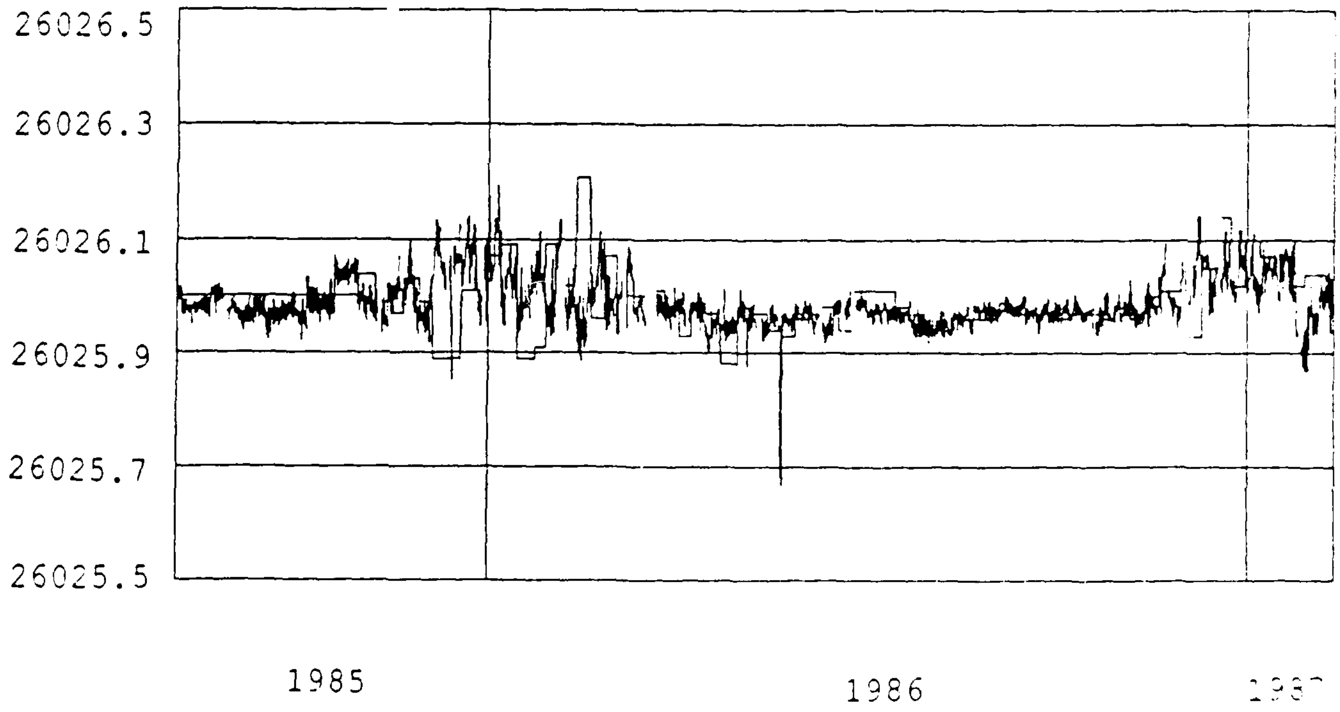


HANSCOM'S FOUR HOUR AVERAGES

WHISKEE BASELINE

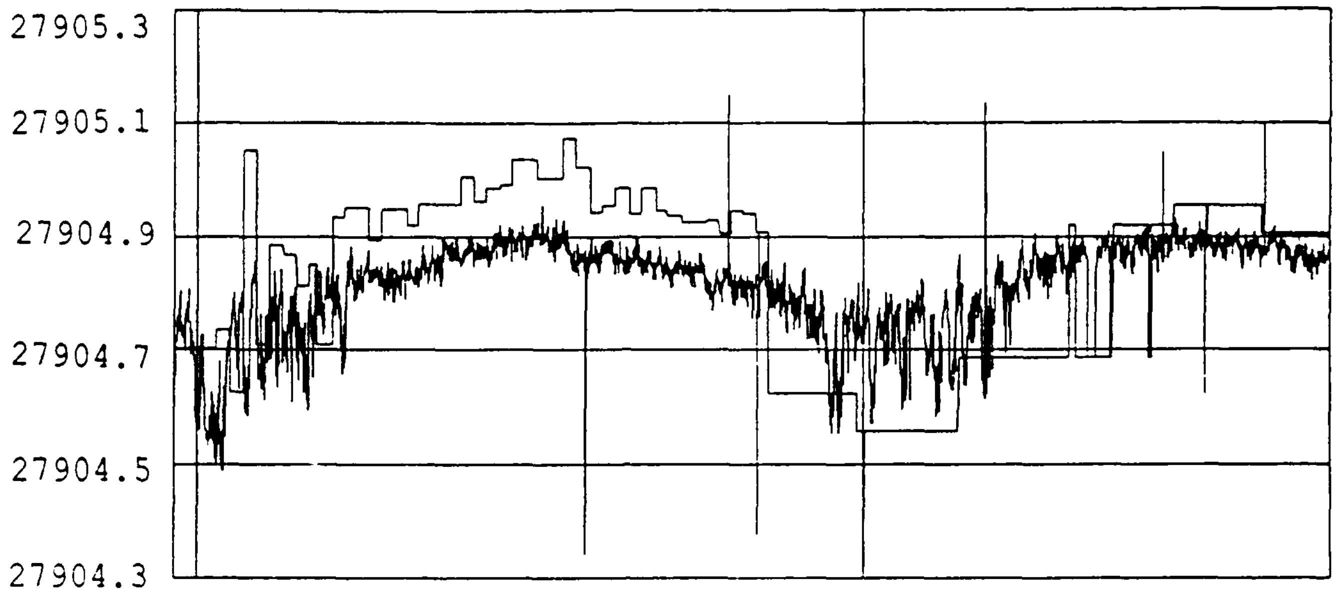


XRAY BASELINE

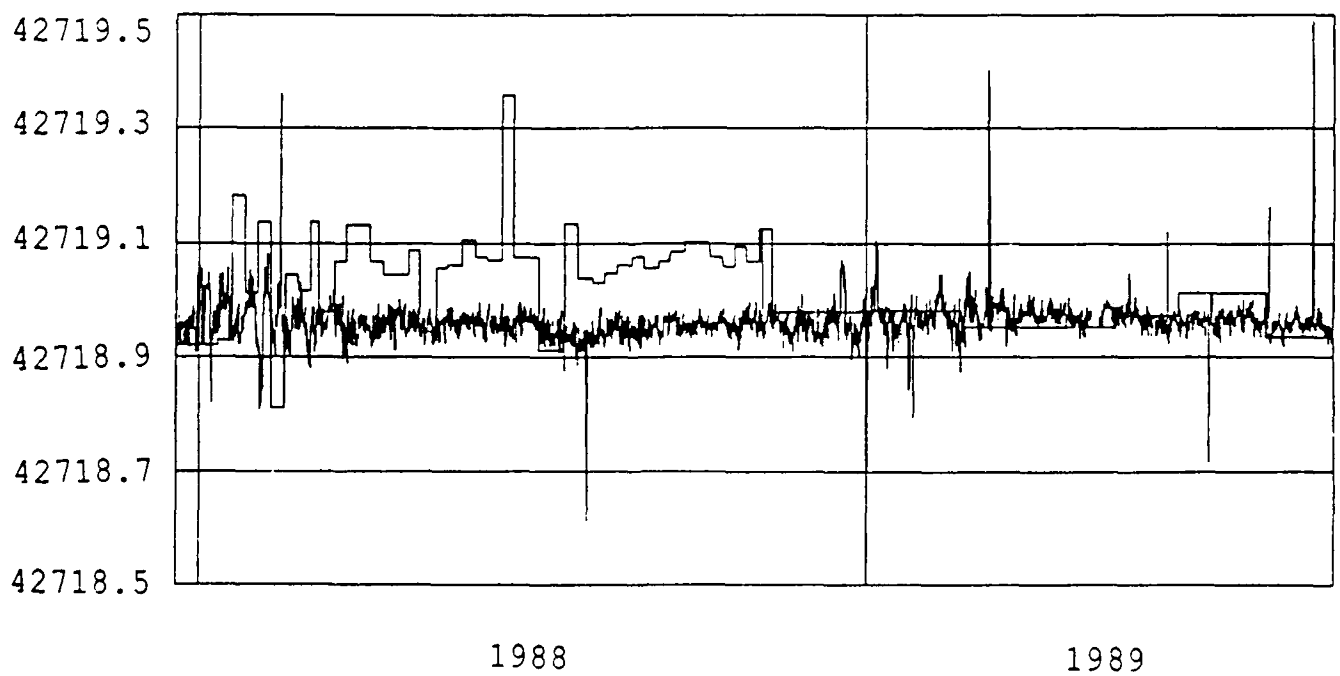


MANASSAS' FOUR HOUR AVERAGES

XRAY BASELINE

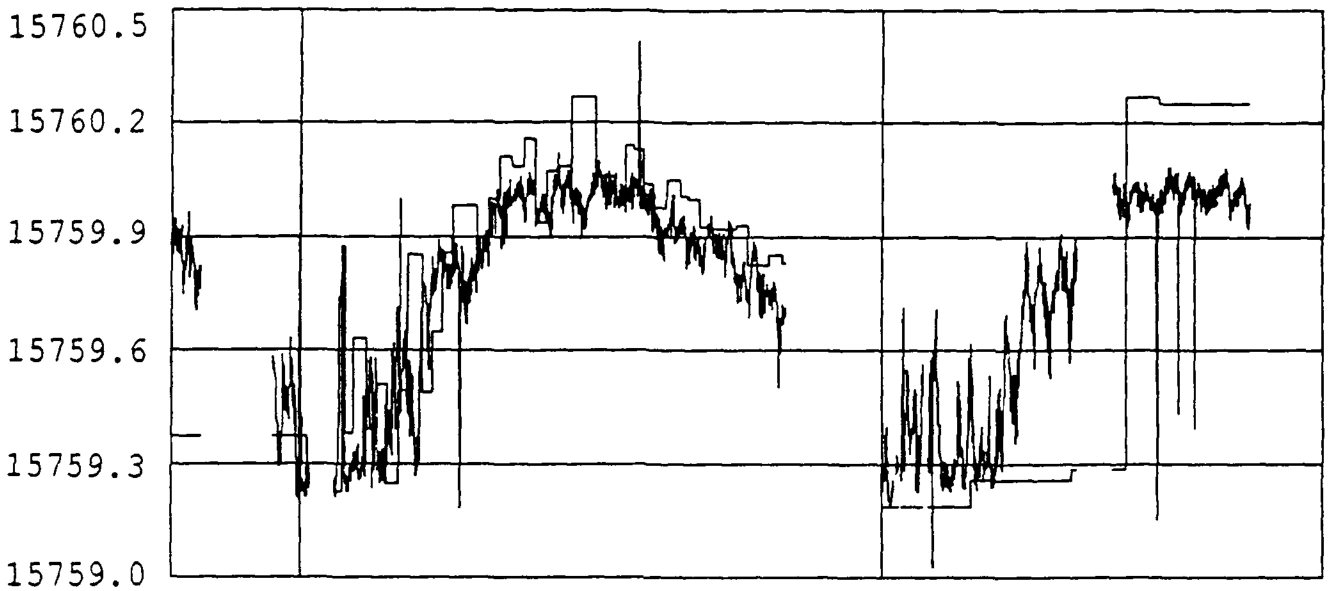


YANKEE BASELINE

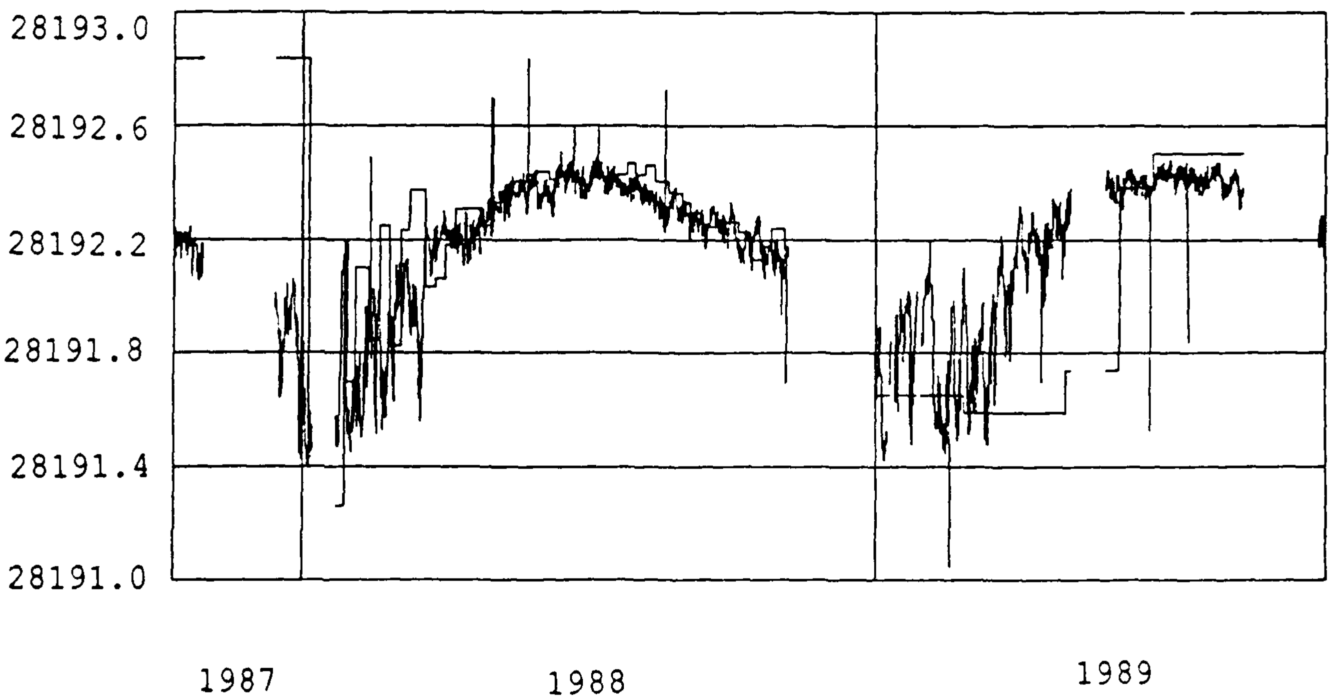


UTICA'S FOUR HOUR AVERAGES

XRAY BASELINE

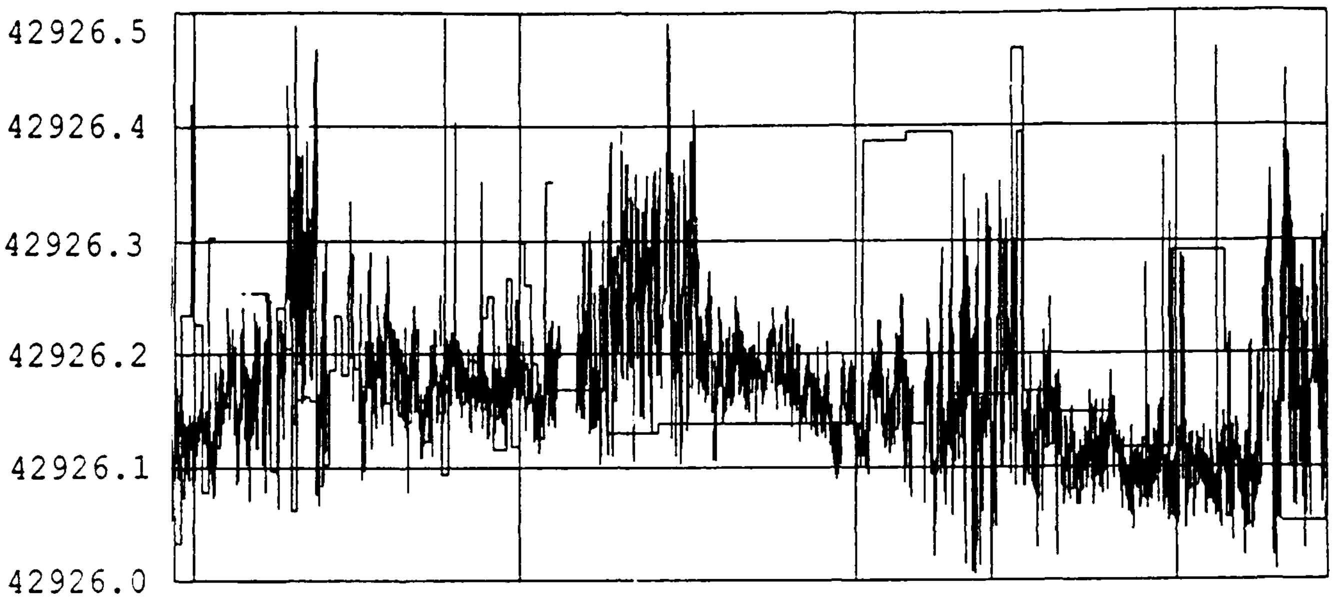


YANKEE BASELINE

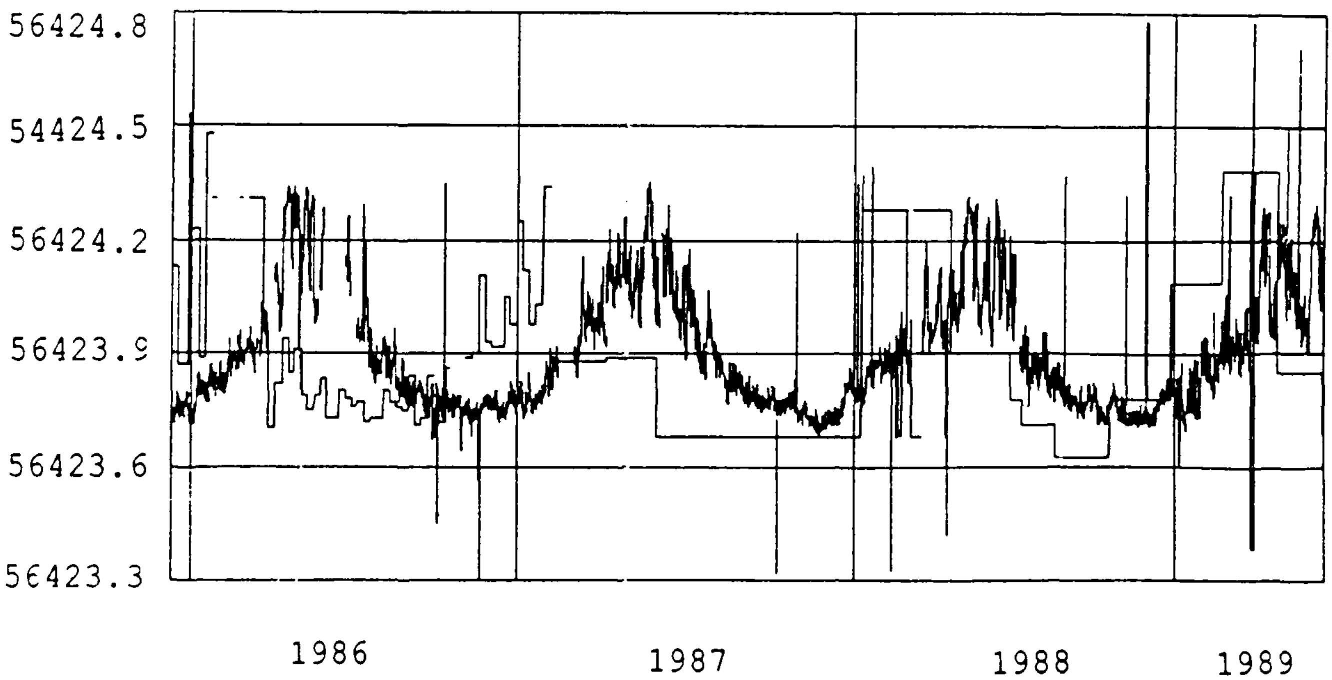


OHIO STATE'S FOUR HOUR AVERAGES

YANKEE BASELINE



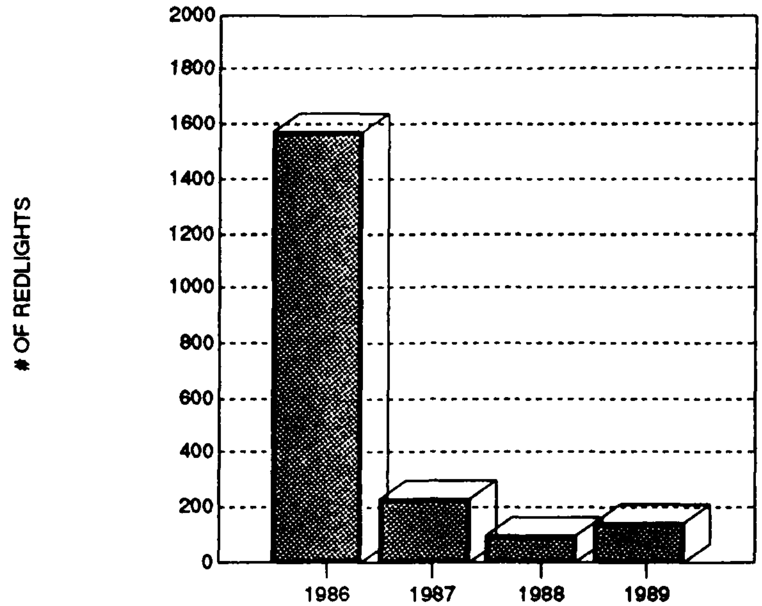
ZULU BASELINE



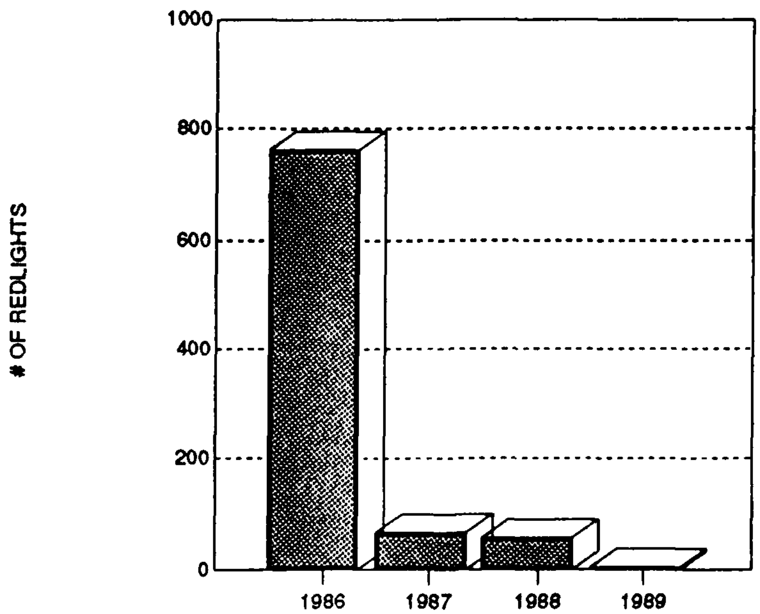
APPENDIX F

AIRPORT ALARMS (1986-9)

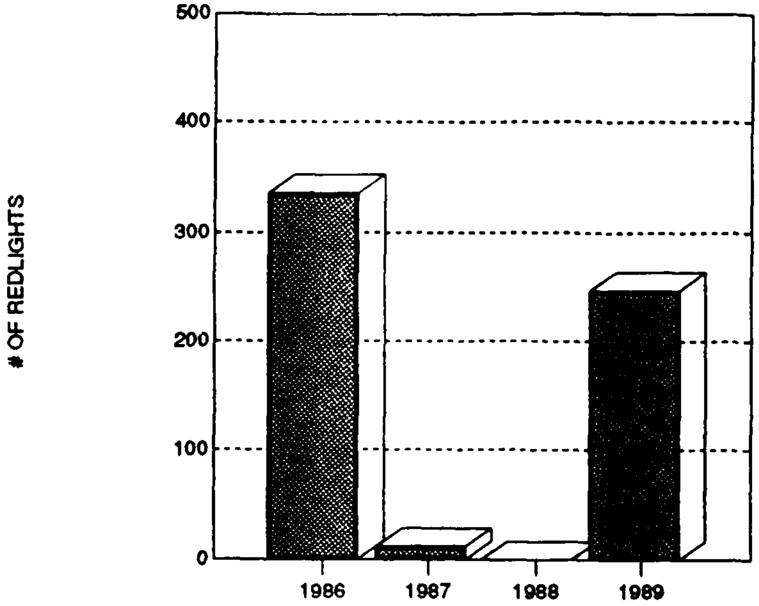
Each participating airport's EIP redlight alarms are shown in bar graphs on the following 17 pages; each bar graph shows one the five major causes (SNR, Distance, Power, Status Bits, and Miscellaneous) by the 4 years of the project (1986 through 1989).



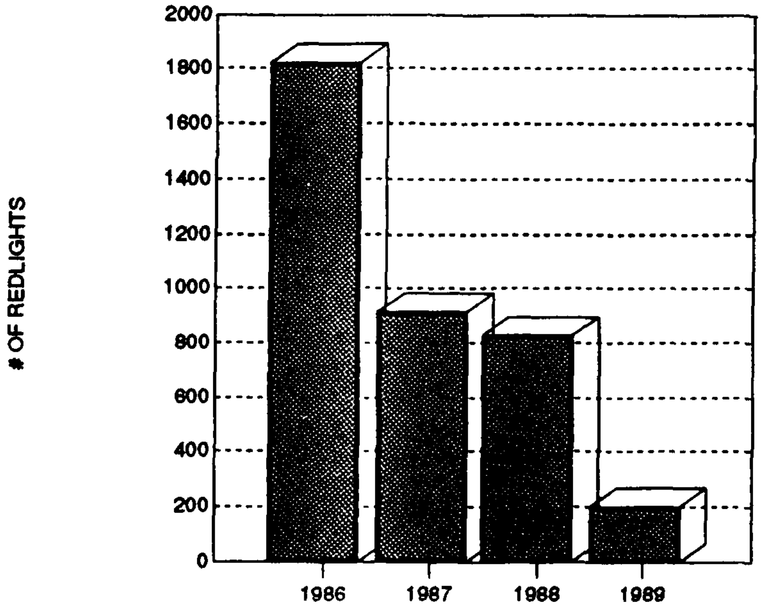
ORLANDO SNR REDLIGHTS



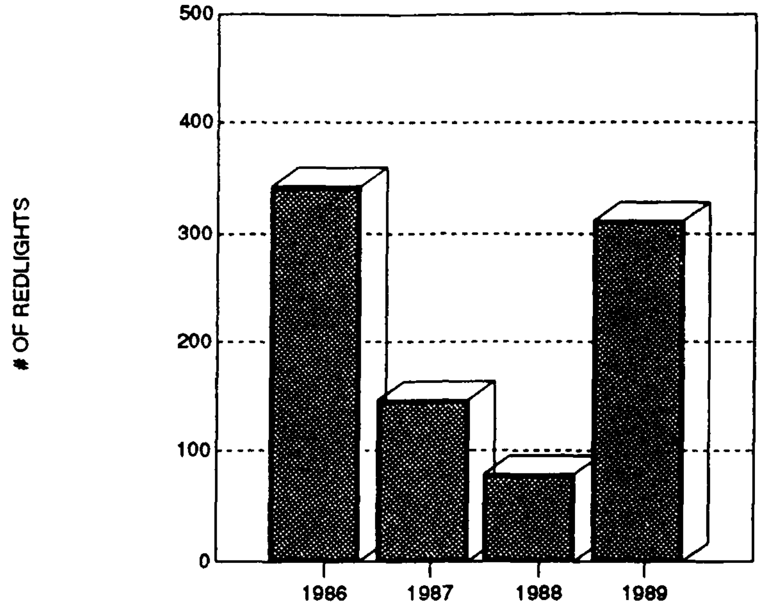
ORLANDO DISTANCE REDLIGHTS



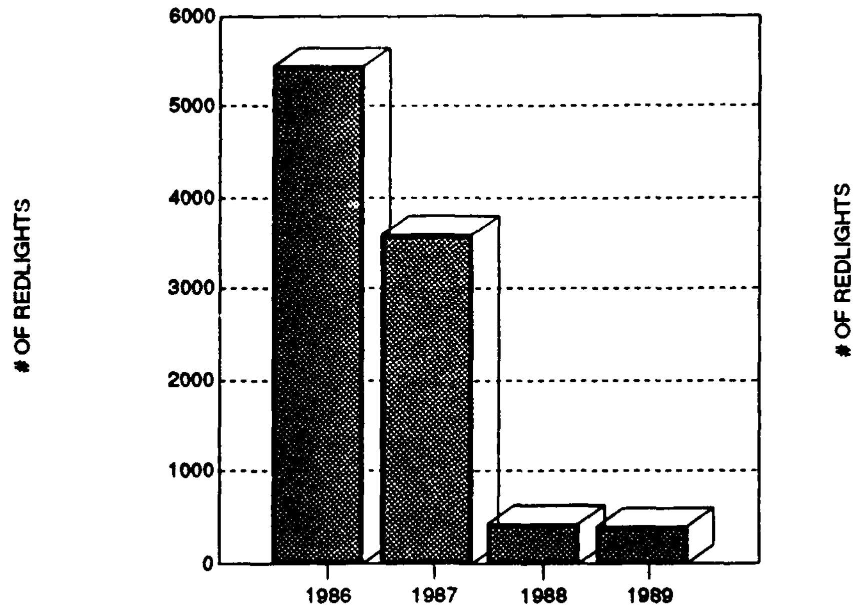
ORLANDO POWER REDLIGHTS



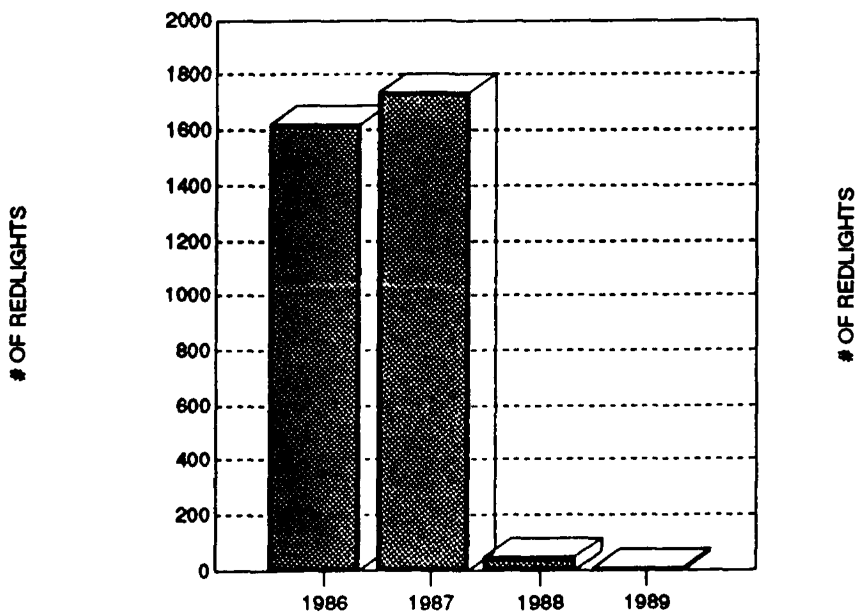
ORLANDO STATUS BITS REDLIGHTS



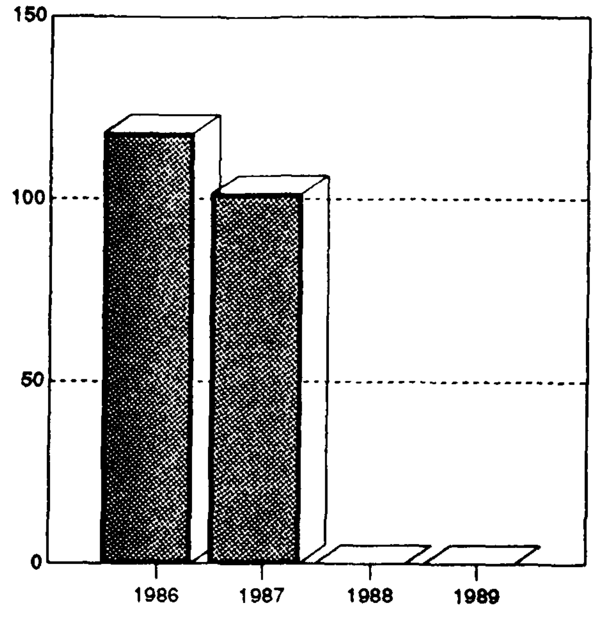
ORLANDO MISCELLANEOUS REDLIGHTS



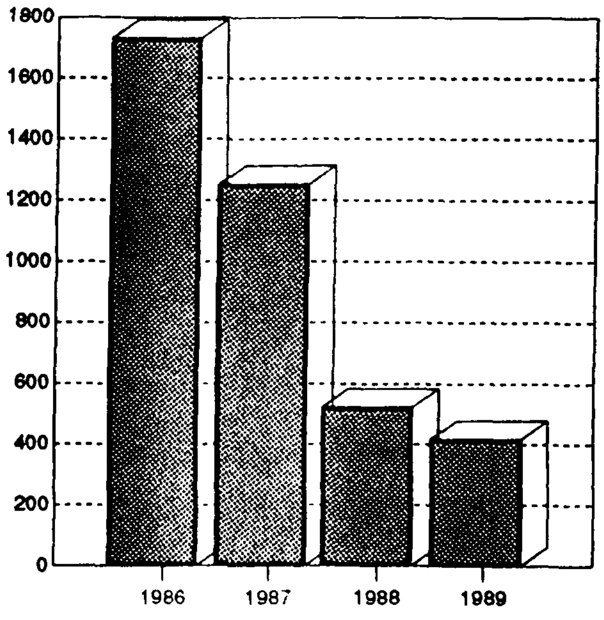
PORTLAND SNR REDLIGHTS



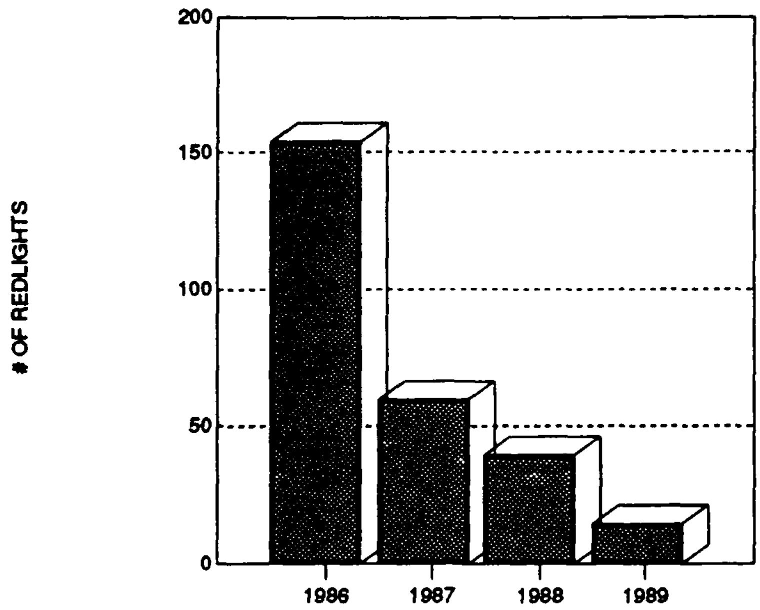
PORTLAND DISTANCE REDLIGHTS



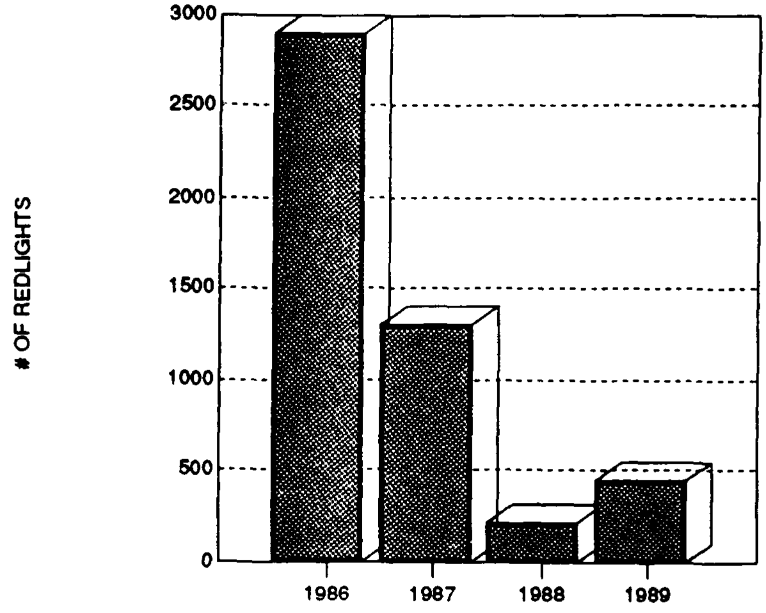
PORTLAND POWER REDLIGHTS



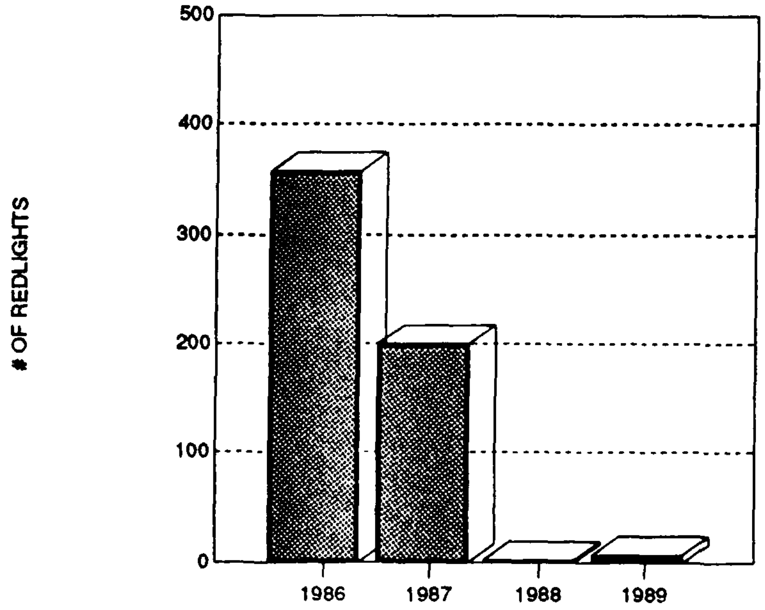
PORTLAND STATUS BITS REDLIGHTS



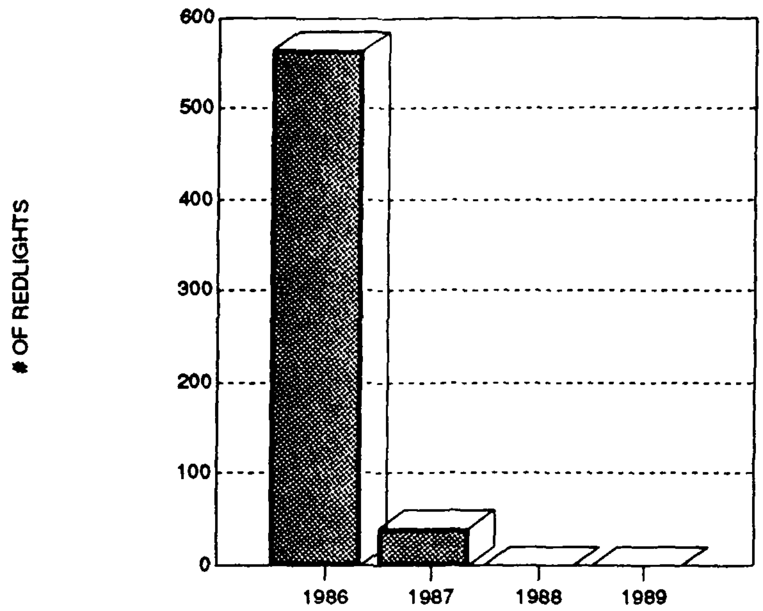
PORTLAND MISCELLANEOUS REDLIGHTS



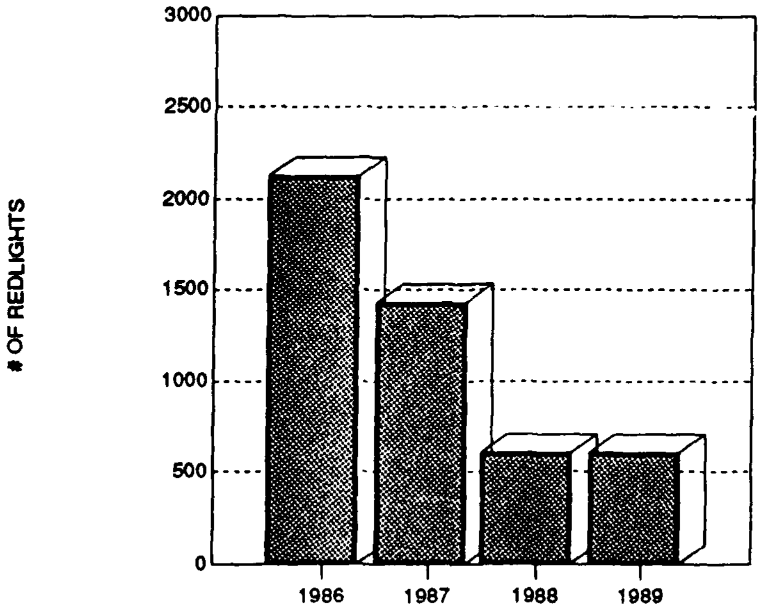
OHIO STATE SNR REDLIGHTS



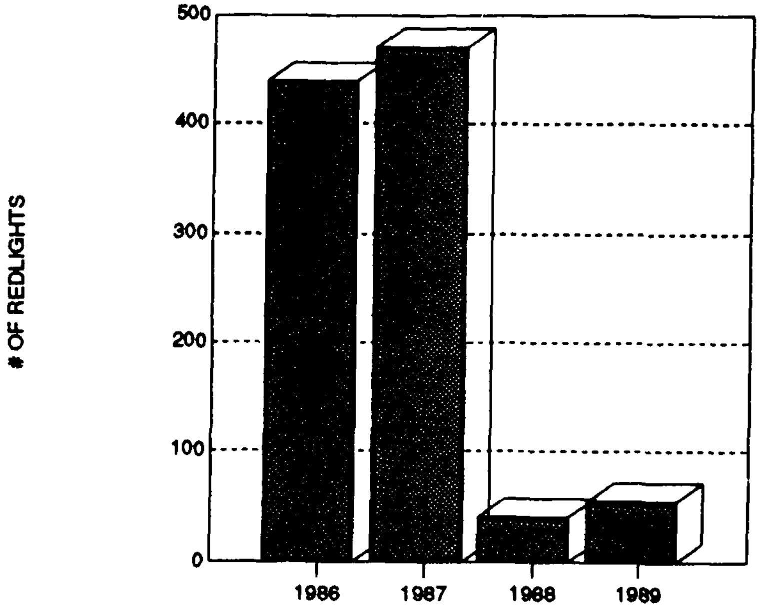
OHIO DISTANCE REDLIGHTS



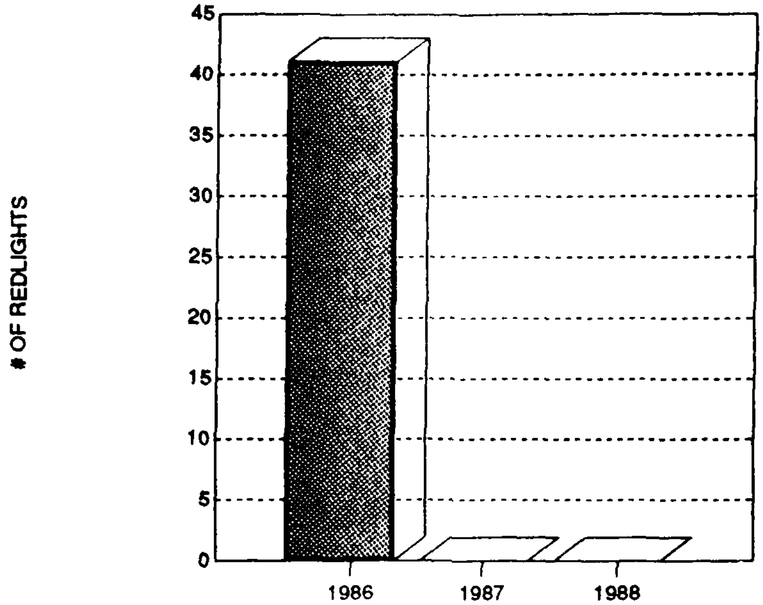
OHIO STATE POWER REDLIGHTS



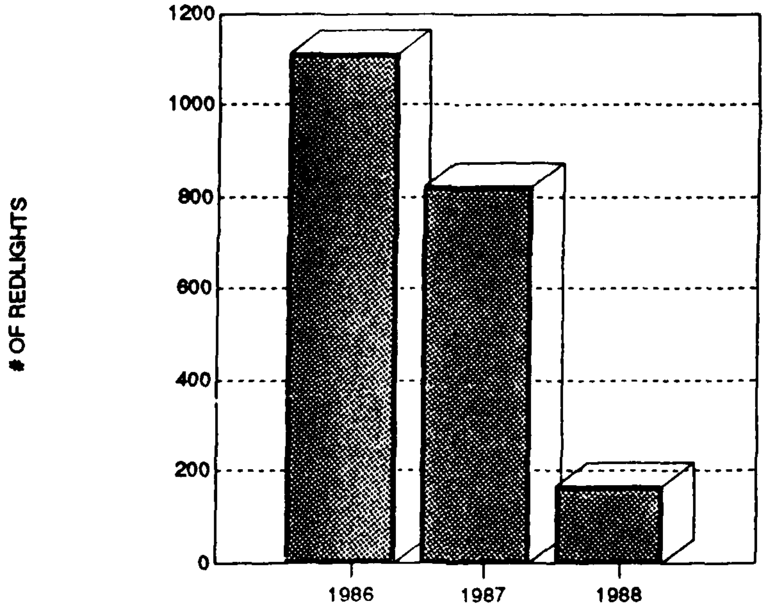
OHIO STATE STATUS BITS REDLIGHTS



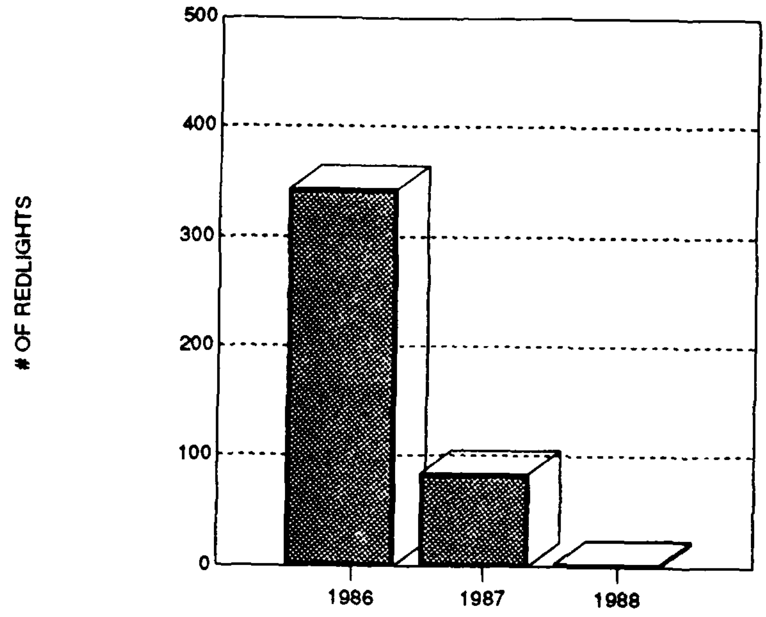
OHIO STATE MISCELLANEOUS REDLIGHTS



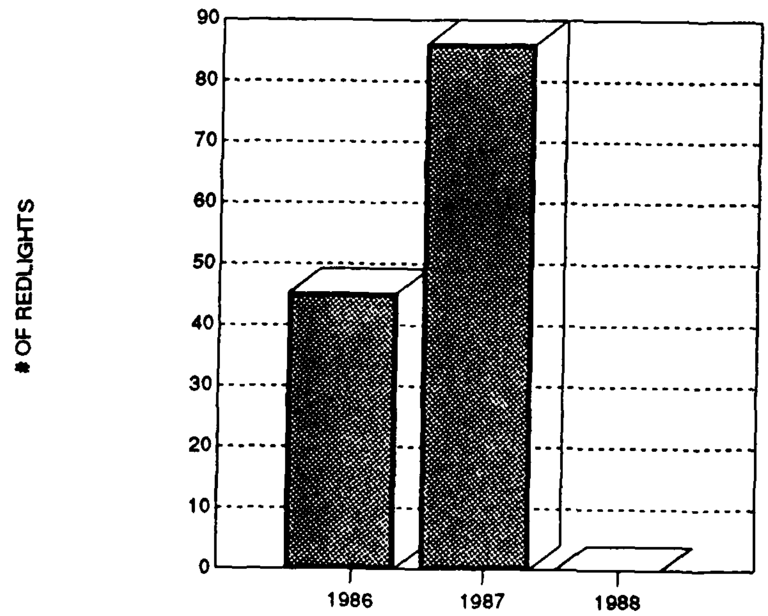
TSC POWER REDLIGHTS



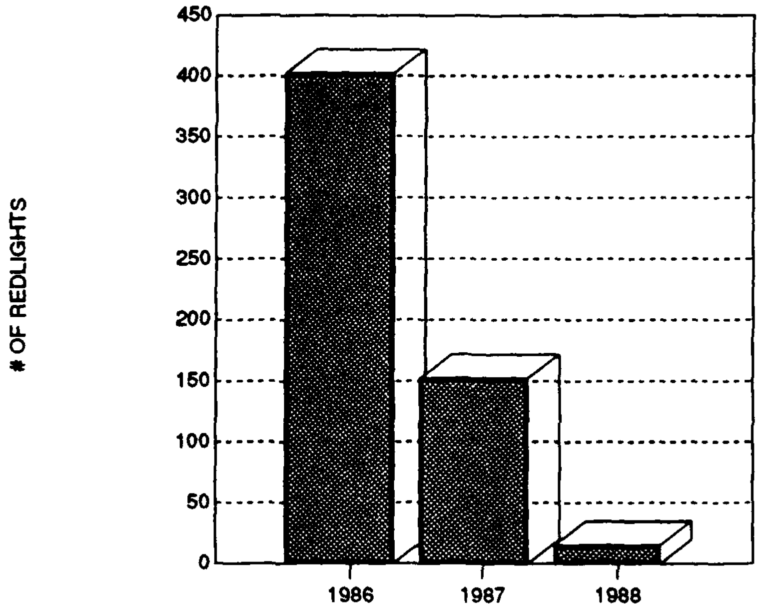
TSC STATUS REDLIGHTS



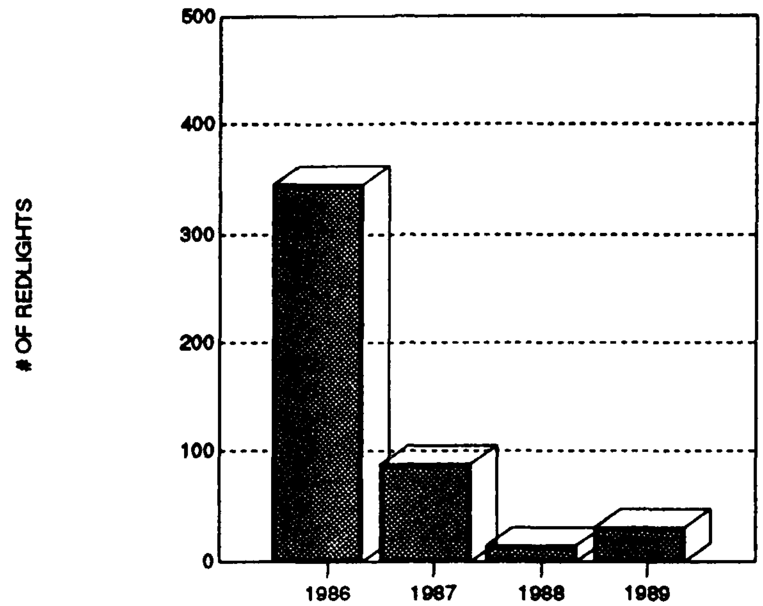
TSC SNR REDLIGHTS



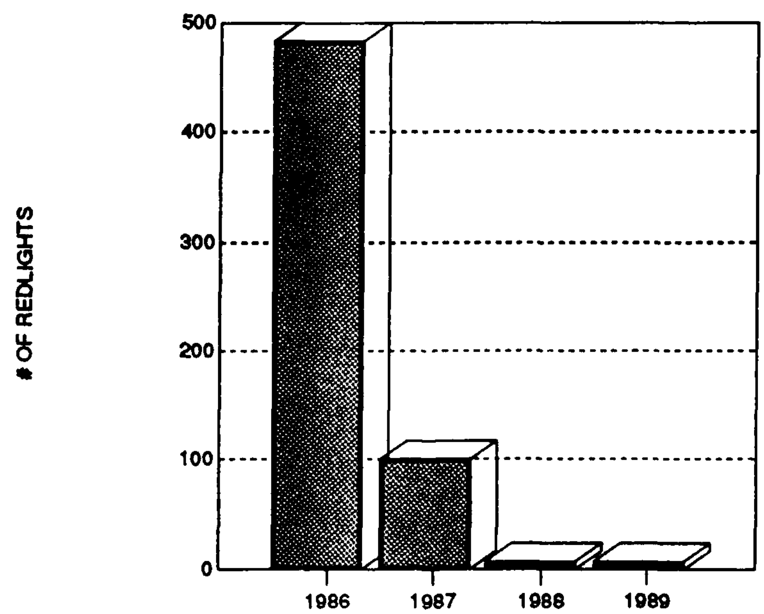
TSC DISTANCE REDLIGHTS



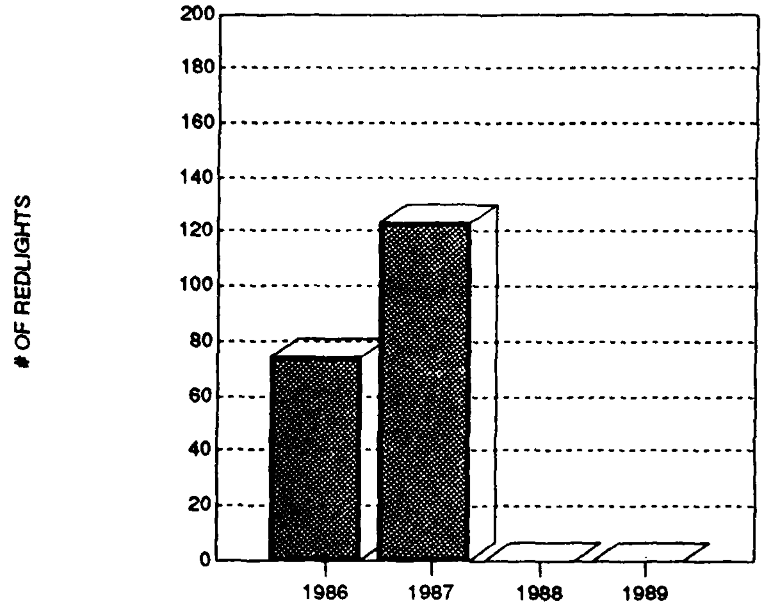
TSC MISCELLANEOUS REDLIGHTS



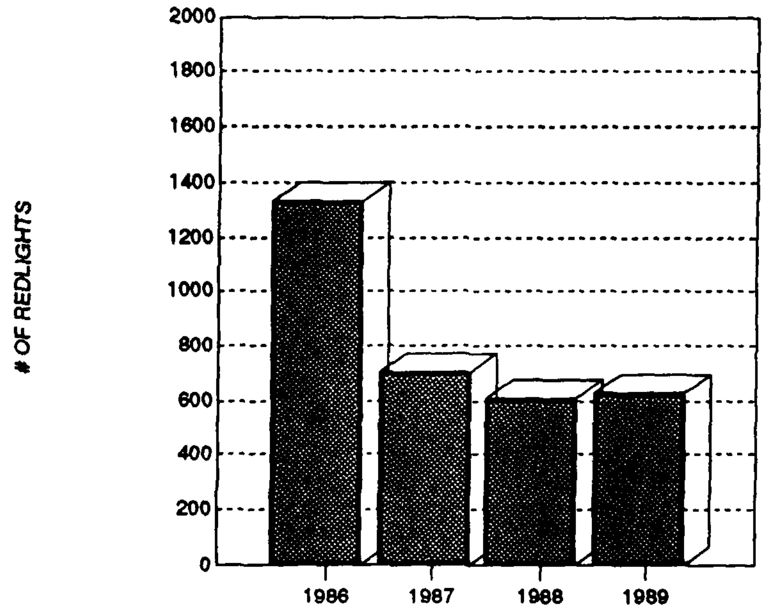
BURLINGTON SNR REDLIGHTS



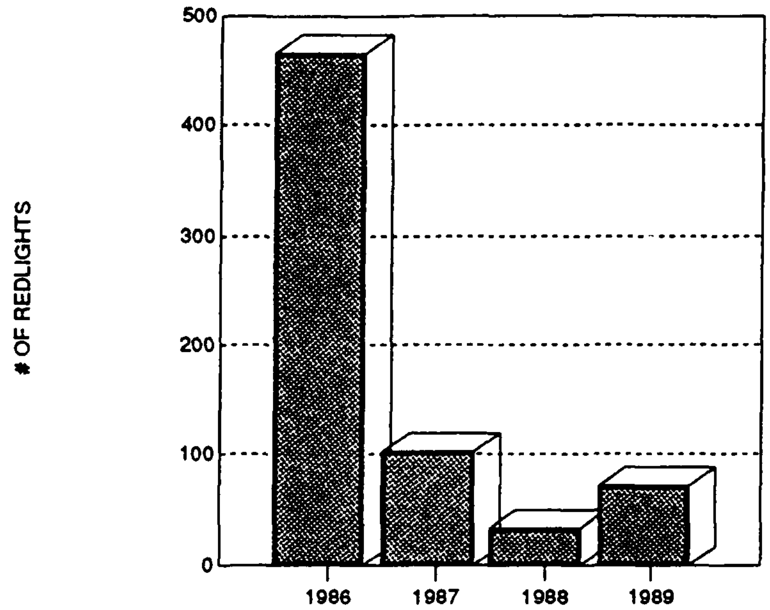
BURLINGTON DISTANCE REDLIGHTS



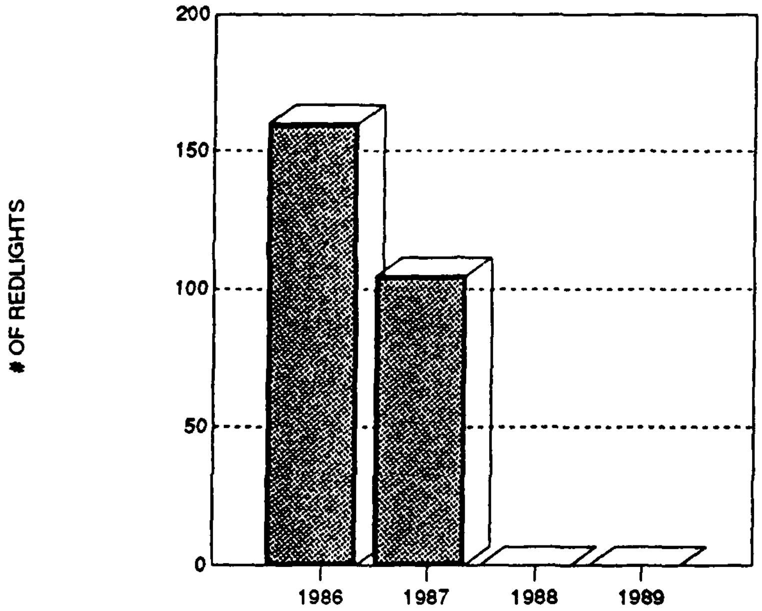
BURLINGTON POWER REDLIGHTS



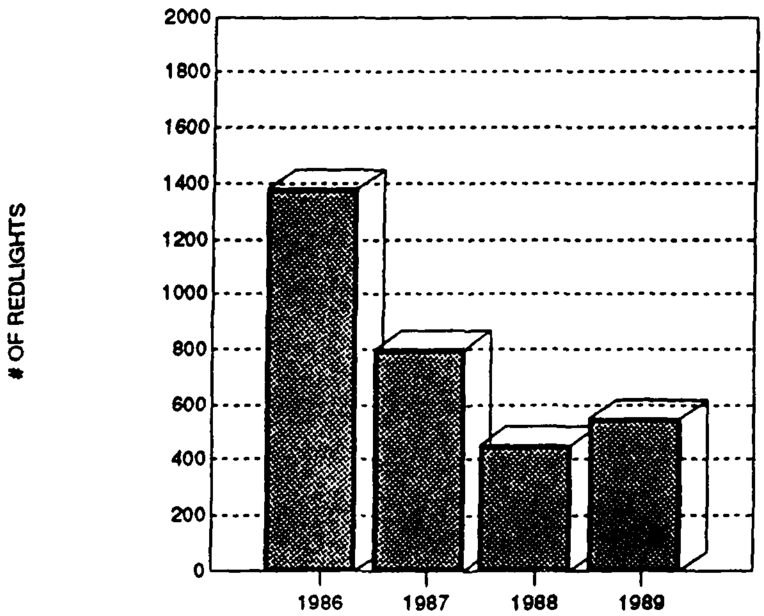
BURLINGTON STATUS BITS REDLIGHTS



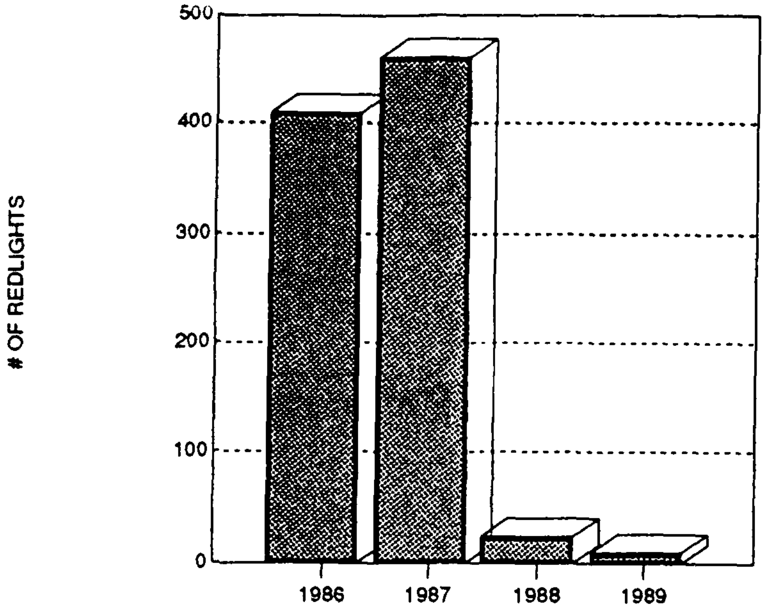
BURLINGTON MISCELLANEOUS REDLIGHTS



LAKEFRONT POWER REDLIGHTS



LAKEFRONT STATUS BITS REDLIGHTS

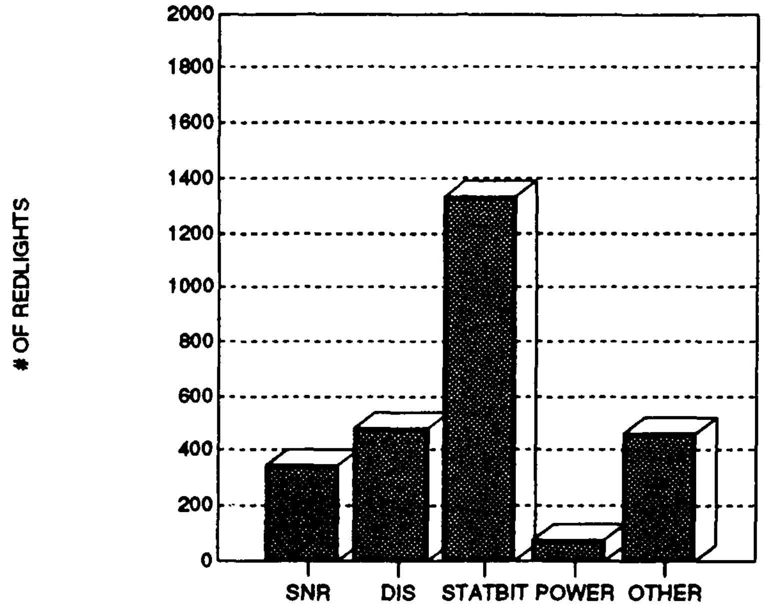


LAKEFRONT DISTANCE REDLIGHTS

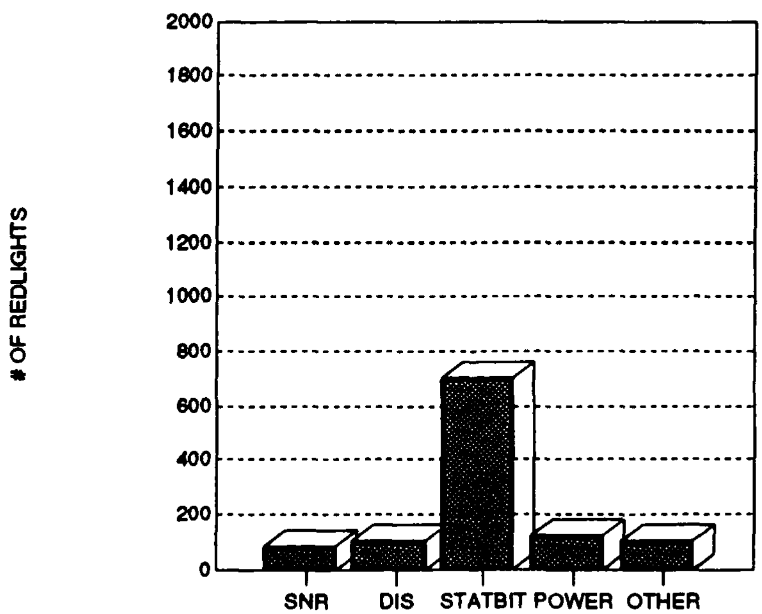
APPENDIX G

ANNUAL AIRPORT ALARM SUMMARIES

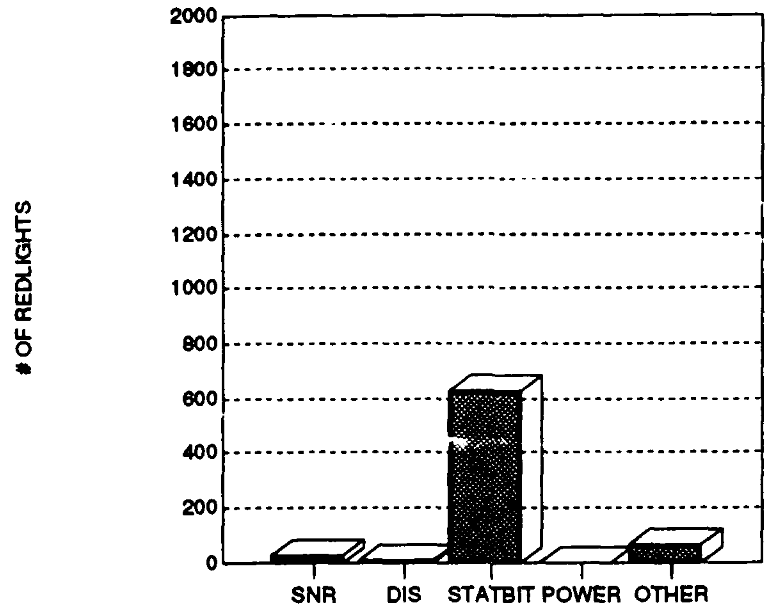
Each airport's EIP redlights are summarized by year (1986-9) in bar graphs on the following pages; the breakdown is by the five major alarm causes (SNR, distance, status bits, power, and miscellaneous.)



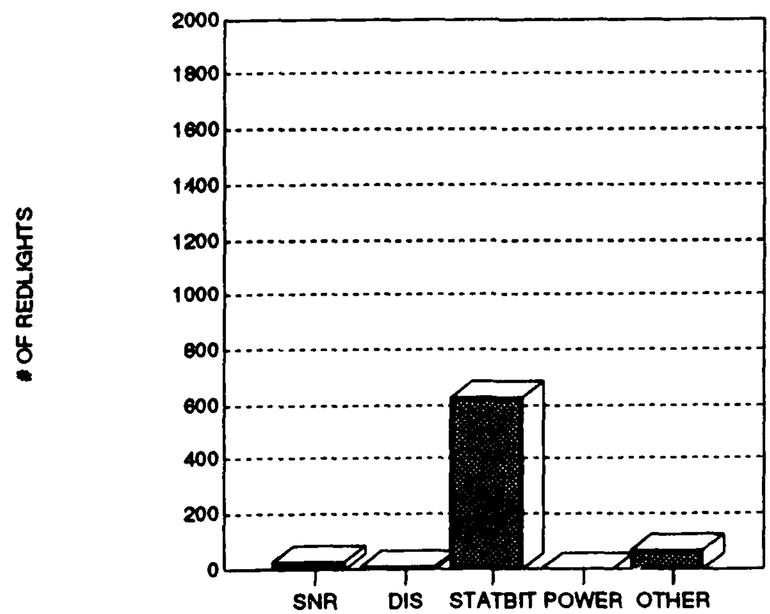
1986 BURLINGTON REDLIGHTS



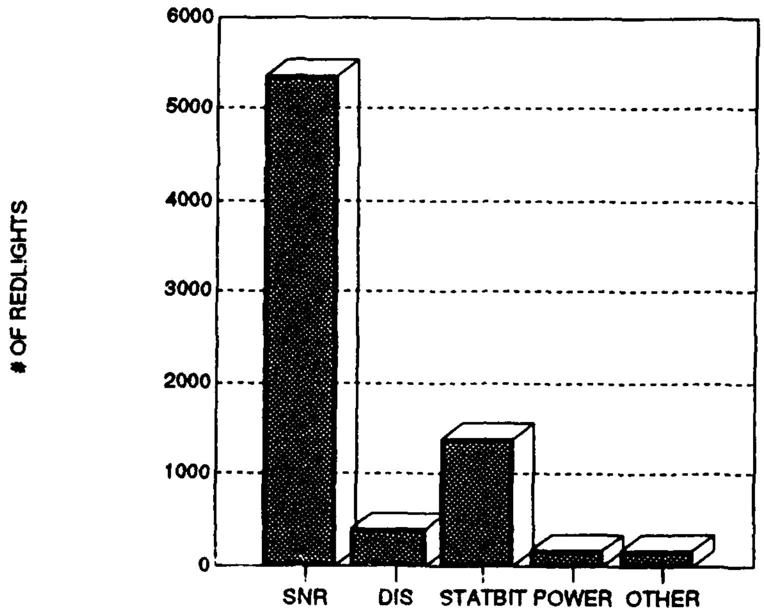
1987 BURLINGTON REDLIGHTS



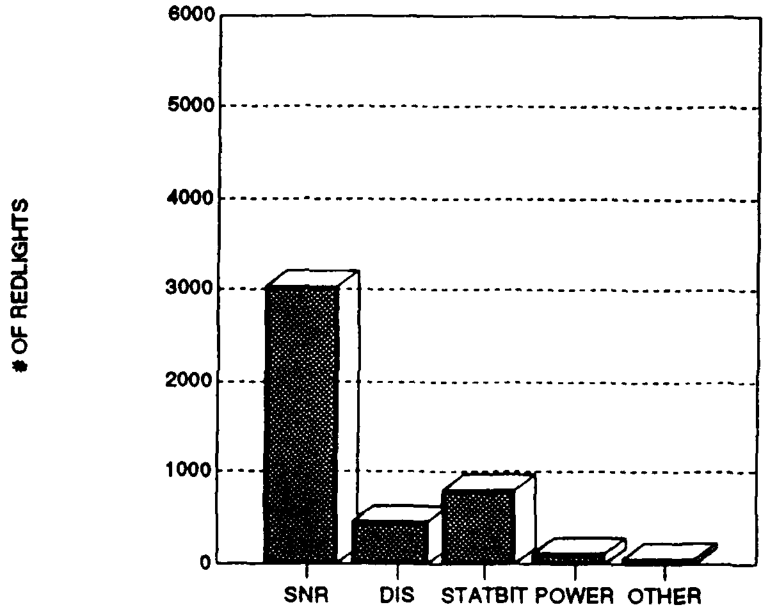
1988 BURLINGTON REDLIGHTS



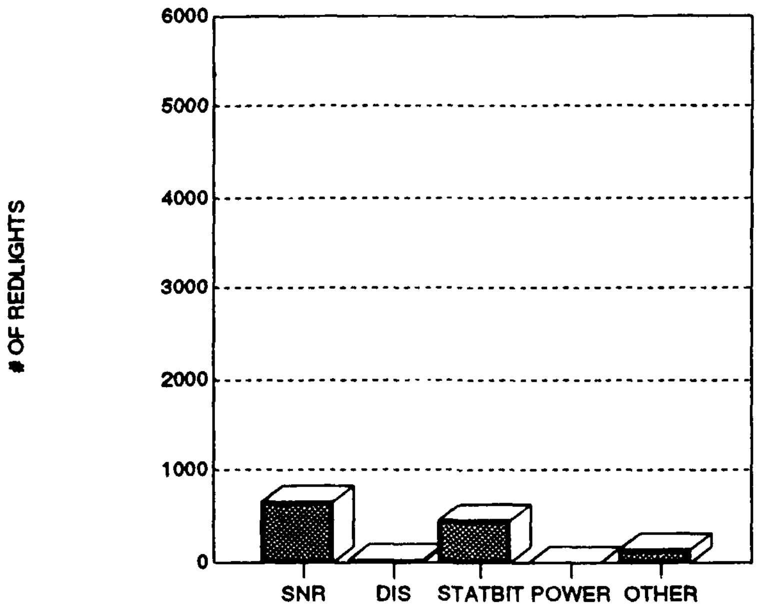
1989 BURLINGTON REDLIGHTS



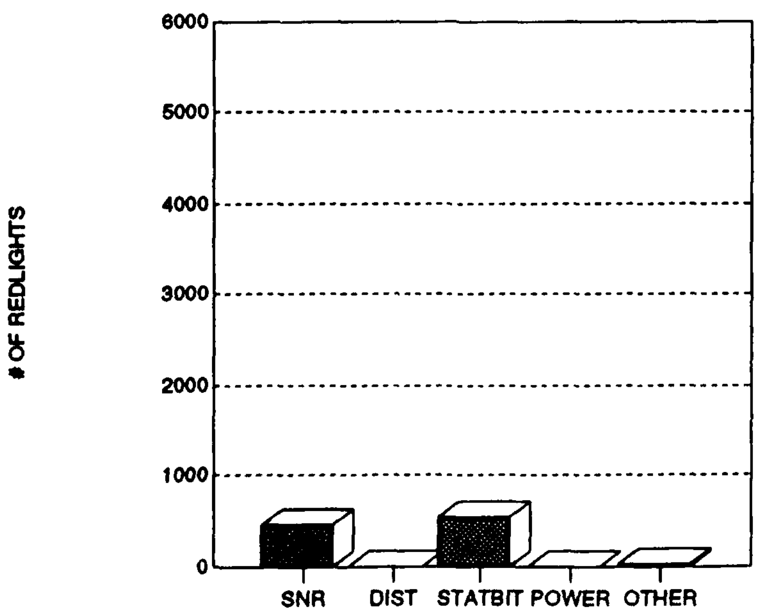
1986 LAKEFRONT REDLIGHTS



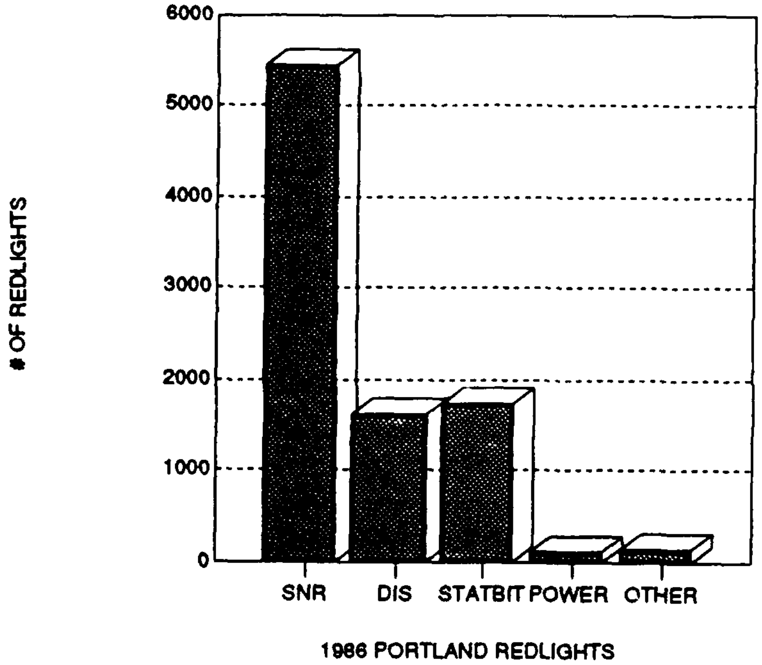
1987 LAKEFRONT REDLIGHTS

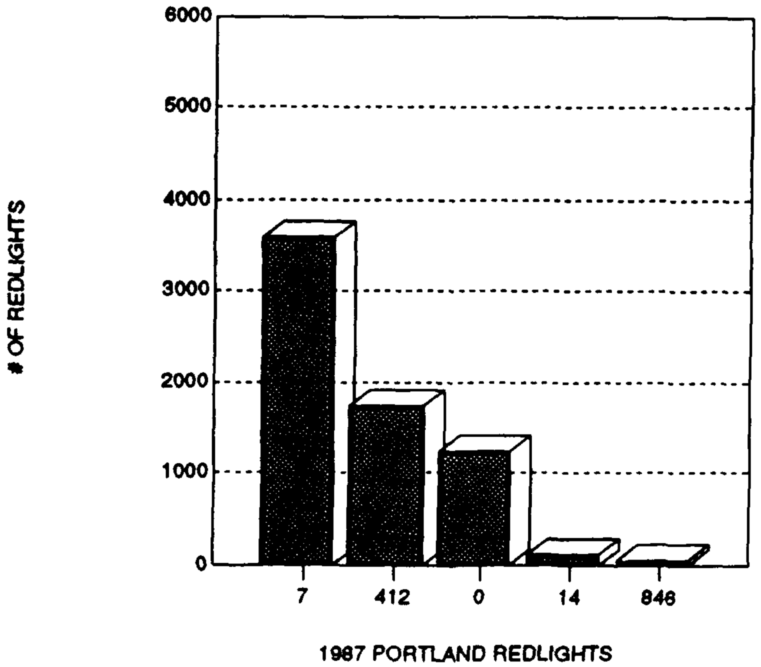


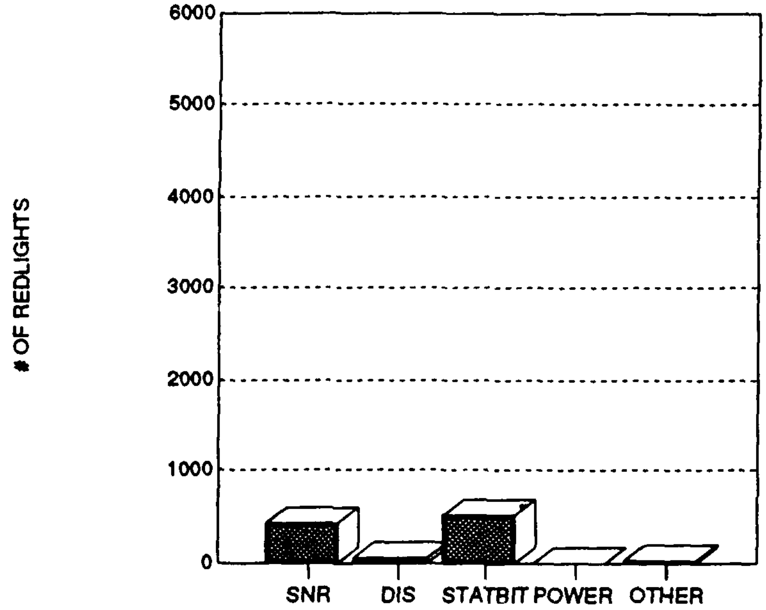
1988 LAKEFRONT REDLIGHTS



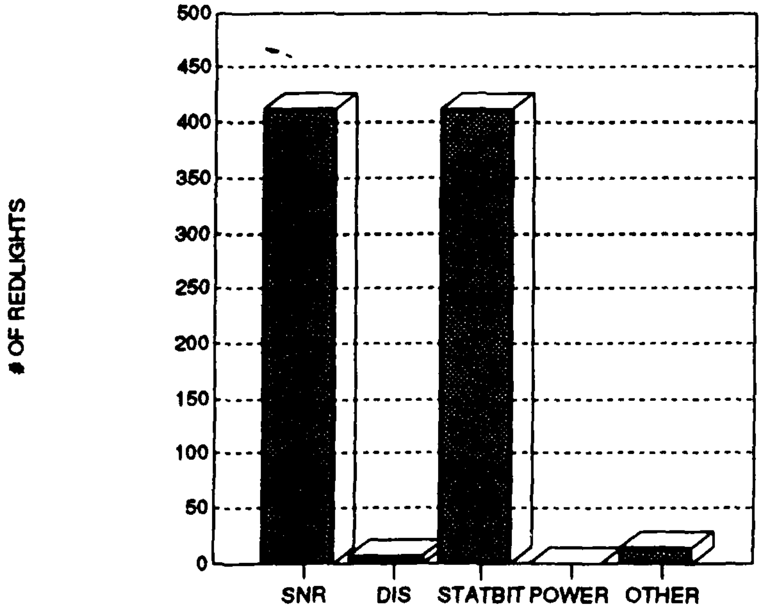
1989 LAKEFRONT REDLIGHTS


6000
5000
4000
3000
2000
1000
0
OF REDLIGHTS
SNR
DIS
STATBIT
POWER
OTHER
1986 PORTLAND REDLIGHTS

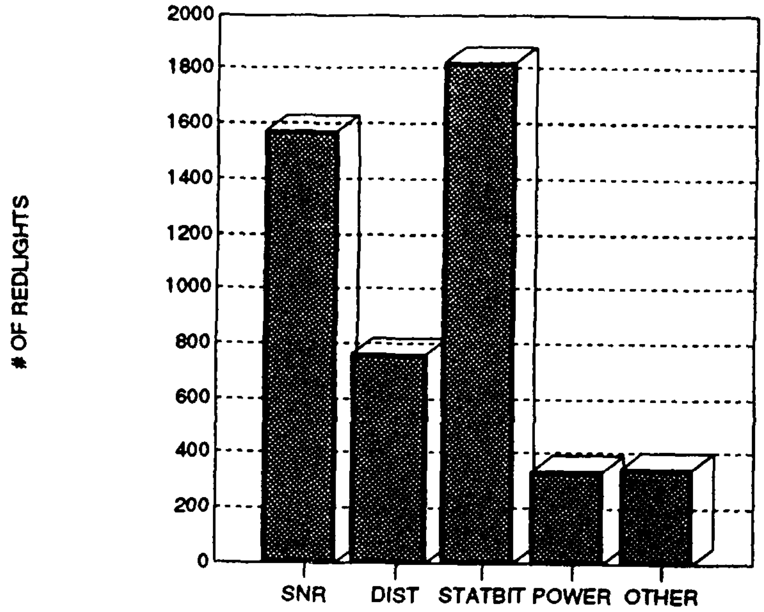

6000
5000
4000
3000
2000
1000
0
OF REDLIGHTS
7
412
0
14
846
1987 PORTLAND REDLIGHTS



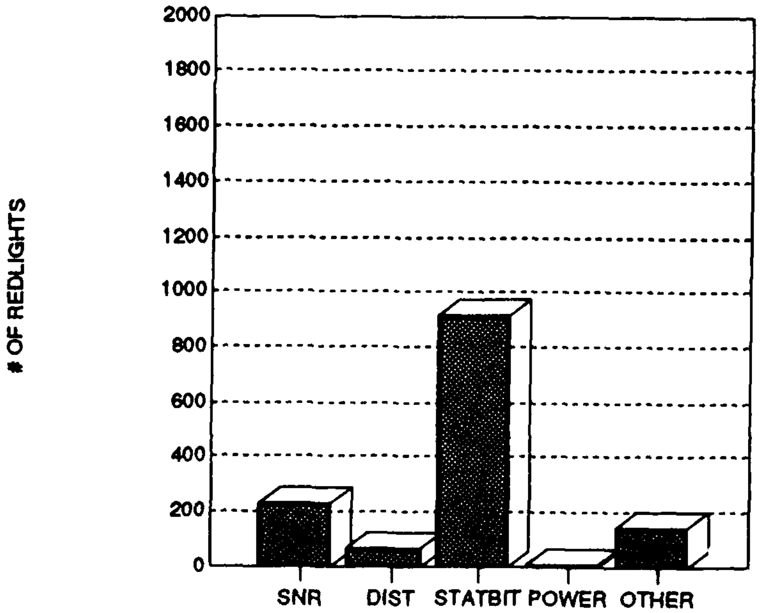
1988 PORTLAND REDLIGHTS



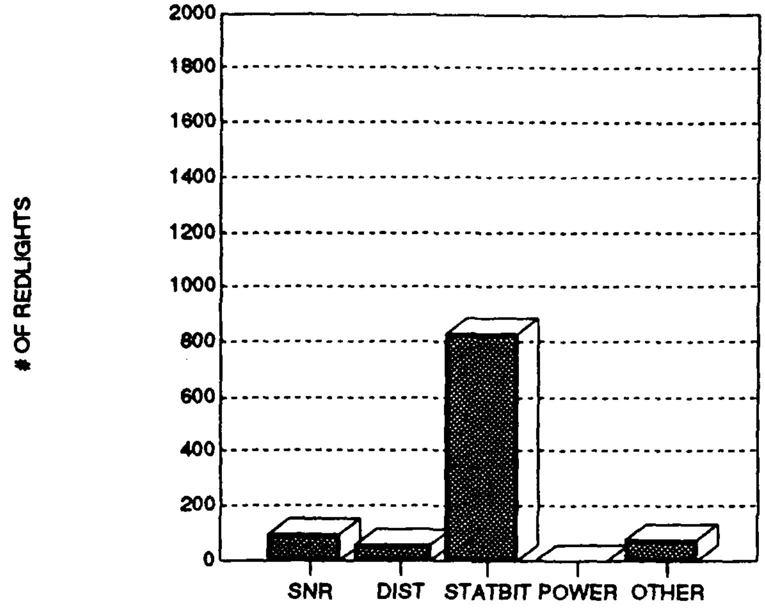
1989 PORTLAND REDLIGHTS



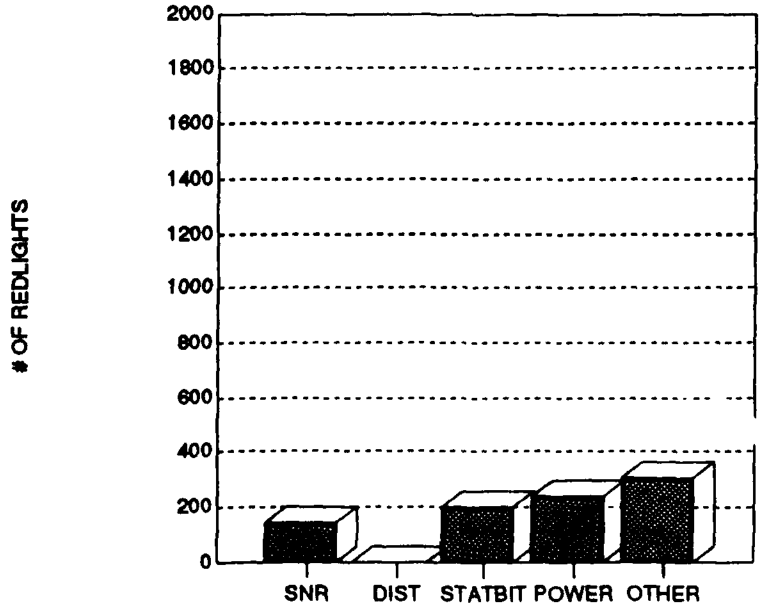
1986 ORLANDO REDLIGHTS



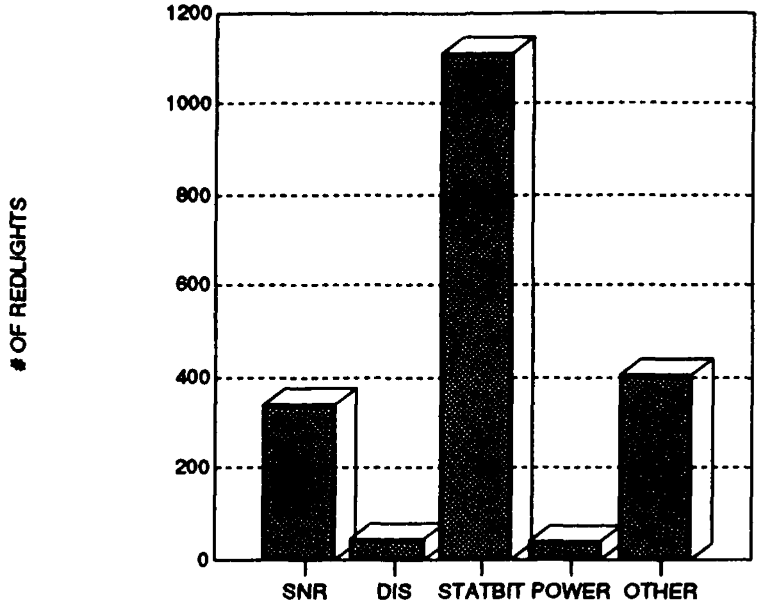
1987 ORLANDO REDLIGHTS



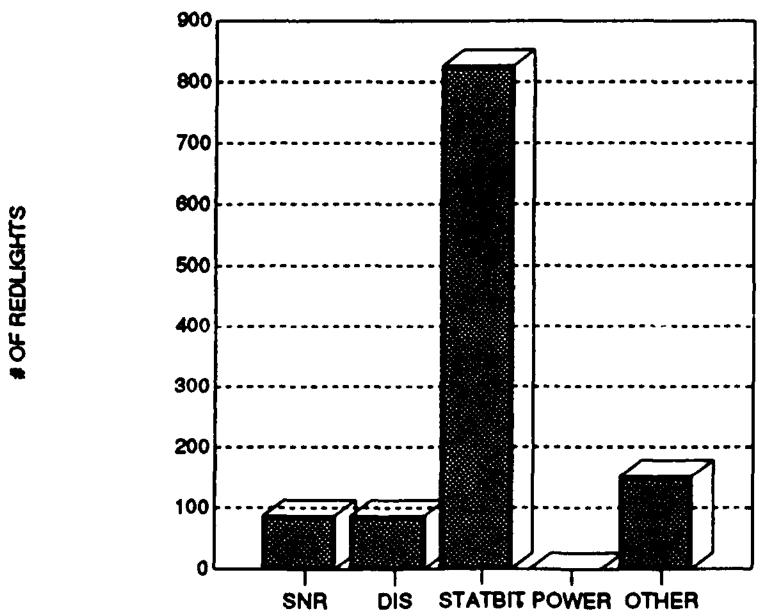
1988 ORLANDO REDLIGHTS



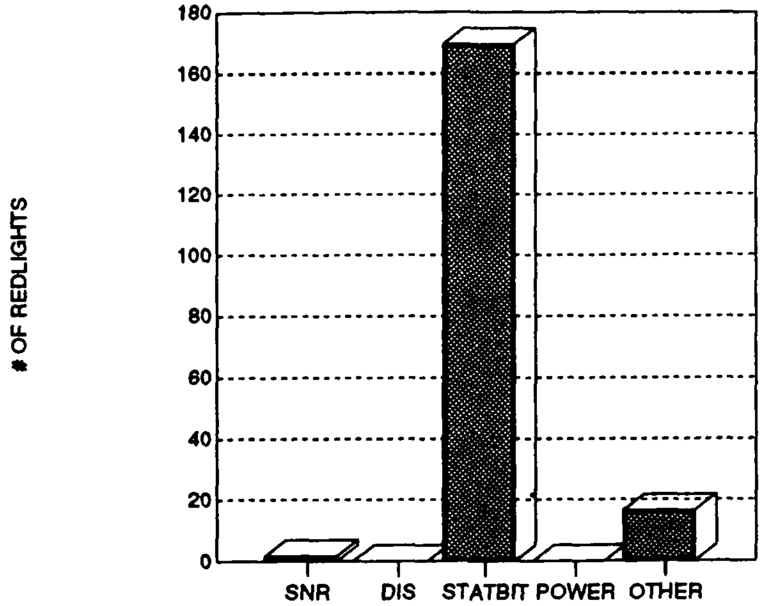
1989 ORLANDO REDLIGHTS



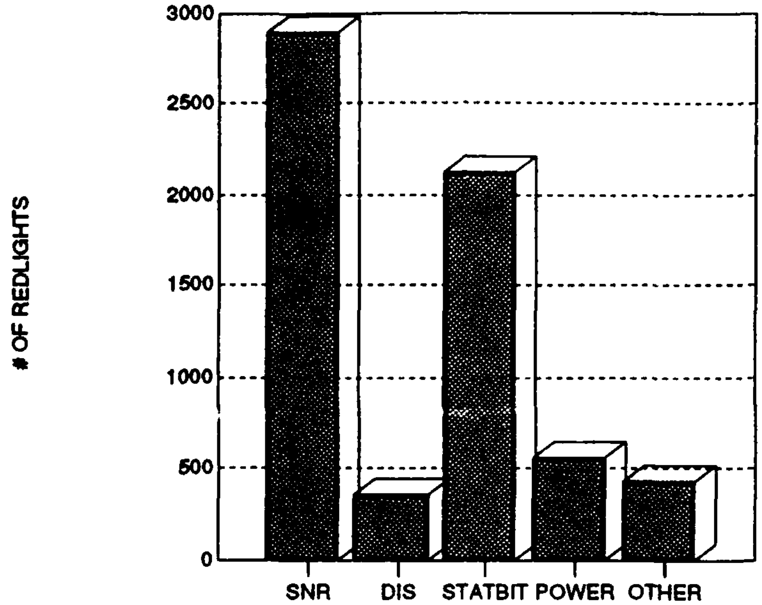
1986 TSC REDLIGHTS



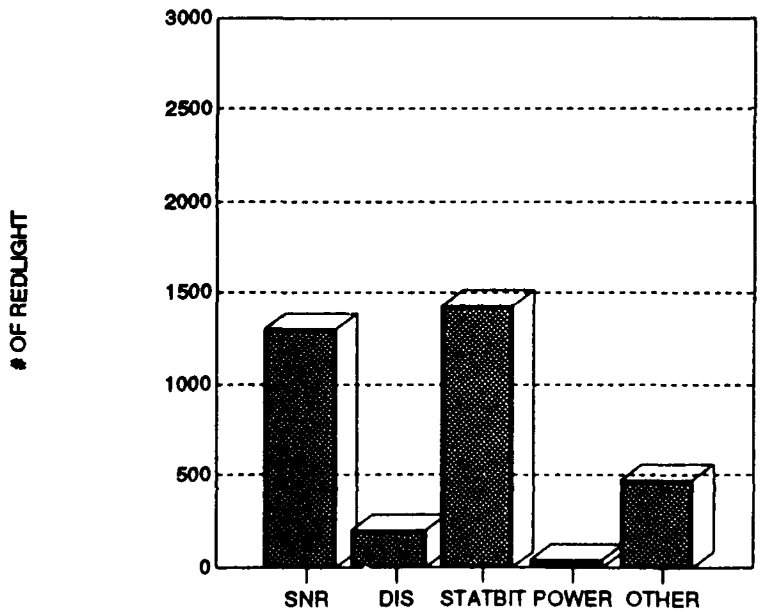
1987 TSC REDLIGHTS



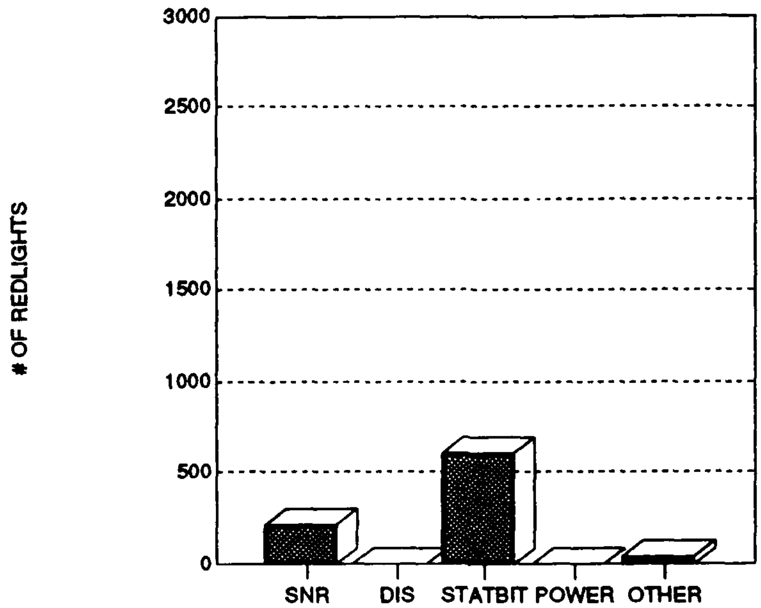
1988 TSC REDLIGHTS (JAN1-JUNE12)



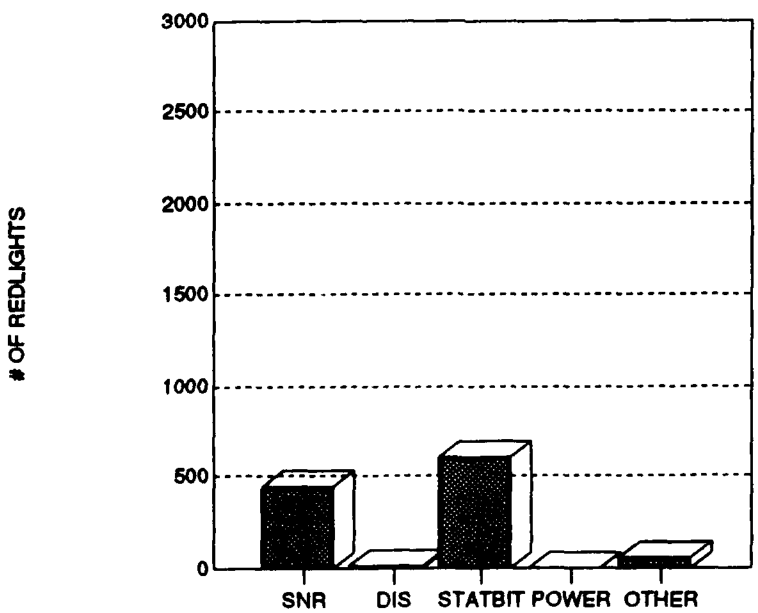
1986 OHIO STATE REDLIGHTS



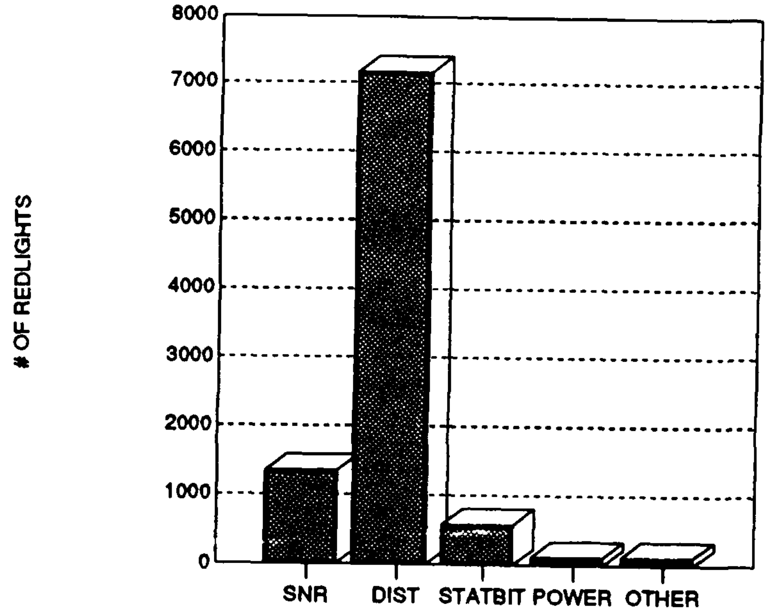
1987 OHIO STATE REDLIGHTS



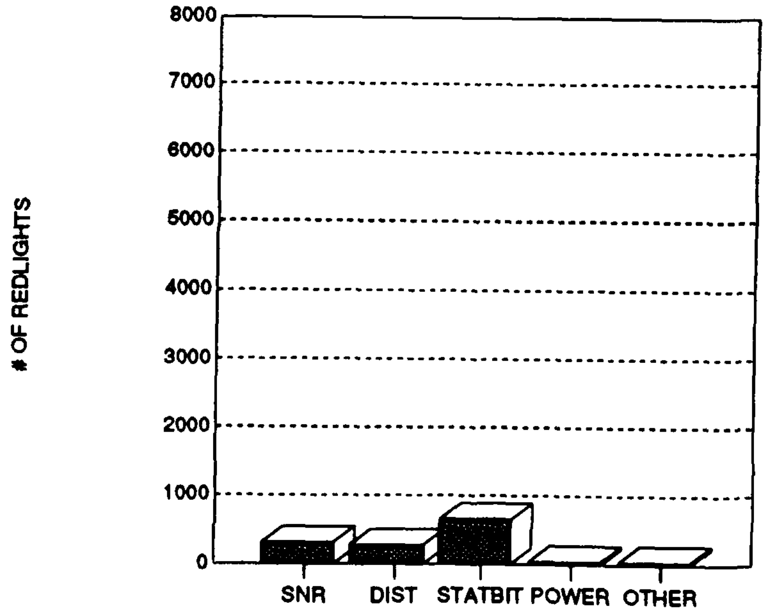
1988 OHIO STATE REDLIGHTS



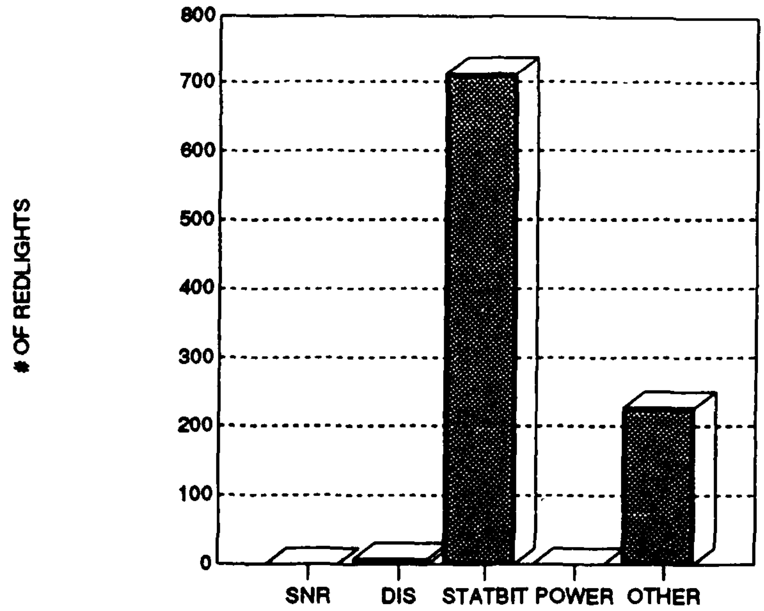
1989 OHIO STATE REDLIGHTS



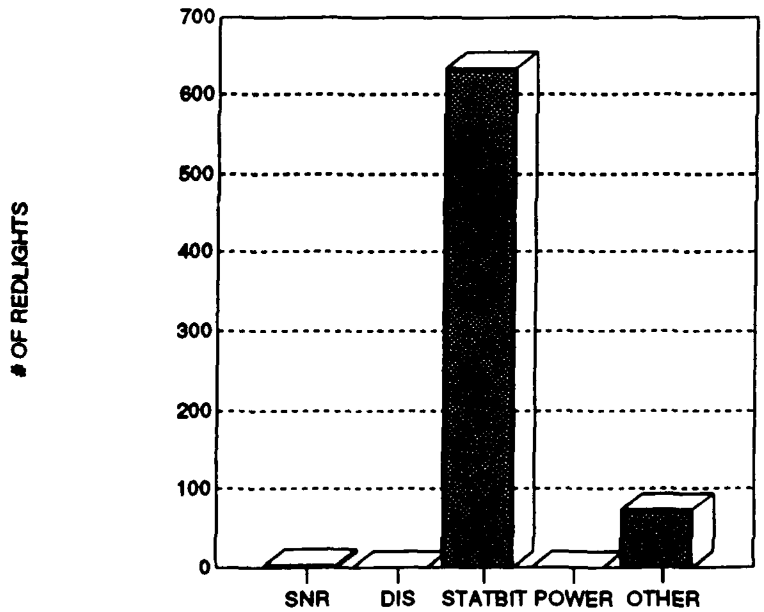
1986 MCNARY REDLIGHTS



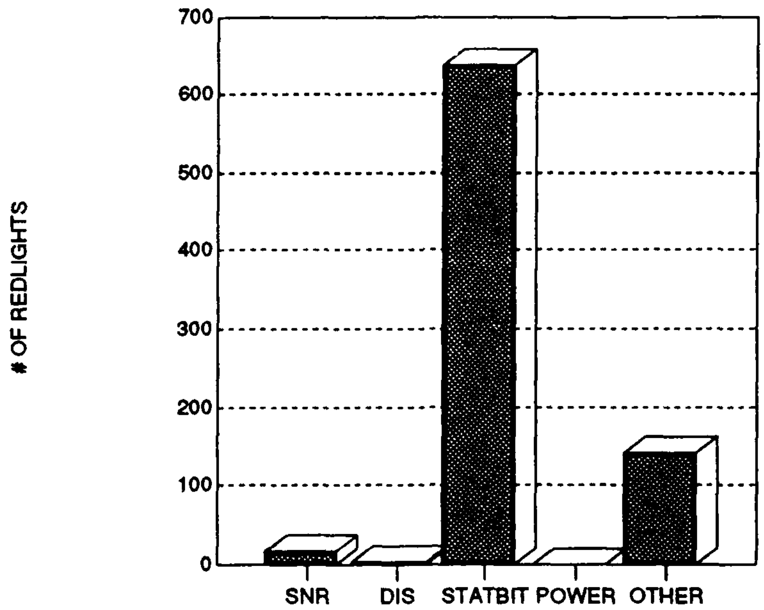
1987 MCNARY REDLIGHTS (JAN1-JUNE27)



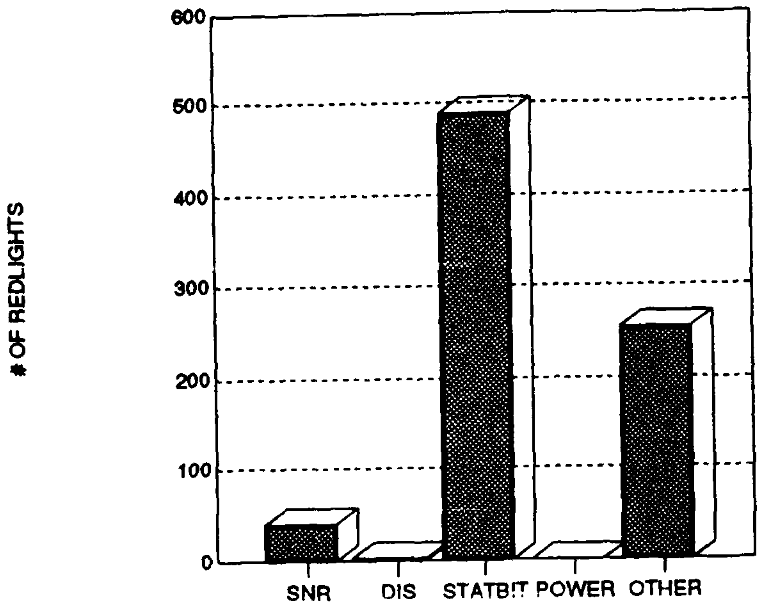
1988 MILLVILLE REDLIGHTS



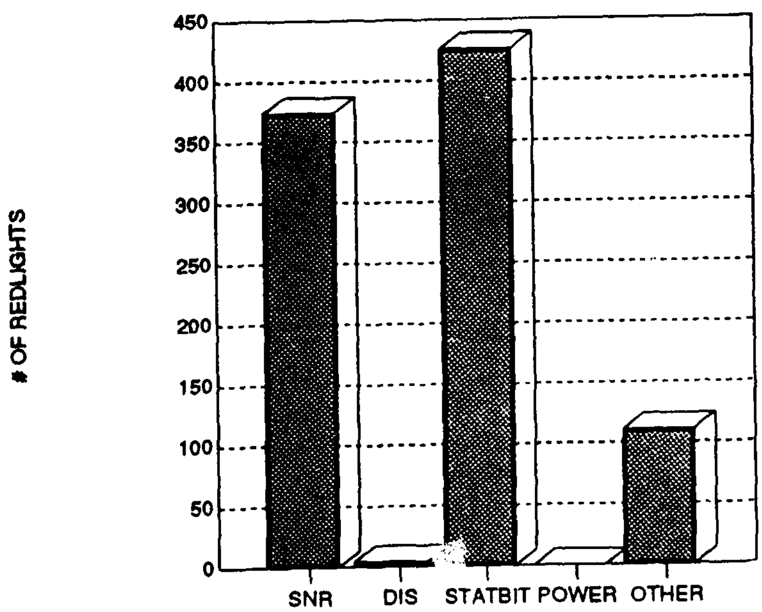
1989 MILLVILLE REDLIGHTS



1989 MANASSAS REDLIGHTS



1988 SOUTH BEND REDLIGHTS



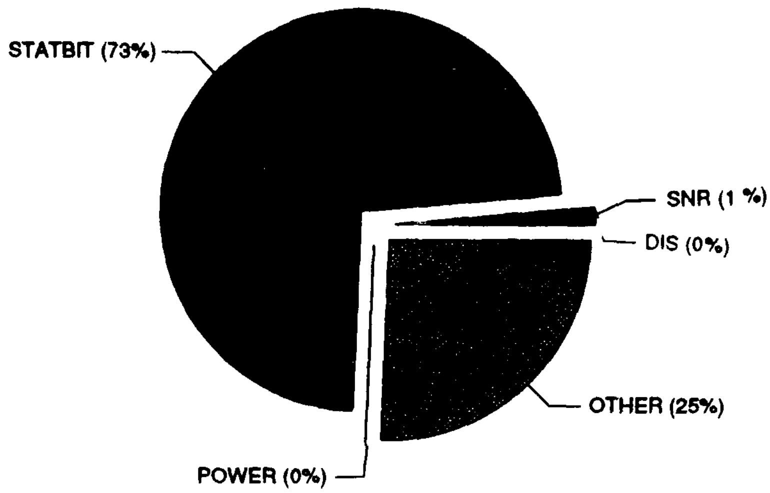
1989 SOUTH BEND REDLIGHTS

APPENDIX H

TOTAL EIP ALARM EVENTS, BY AIRPORT (1986-9)

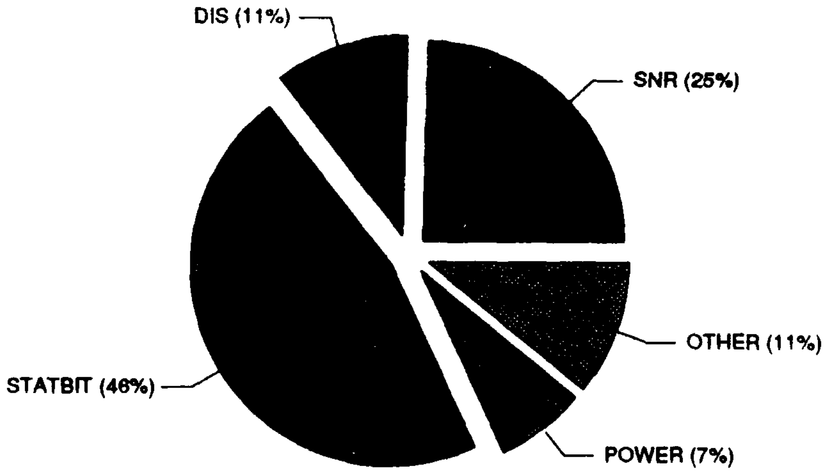
ALARMS RECORDED AT MANASSAS

(1988-1989)(1954 EVENTS)



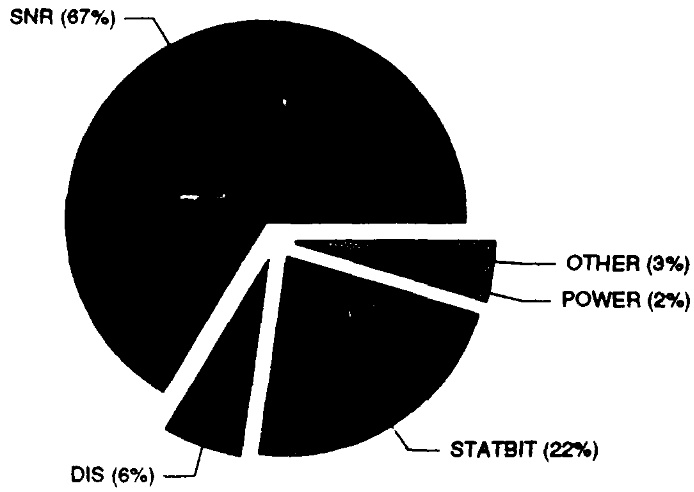
ALARMS RECORDED AT ORLANDO

(1986-1989)(8168 EVENTS)



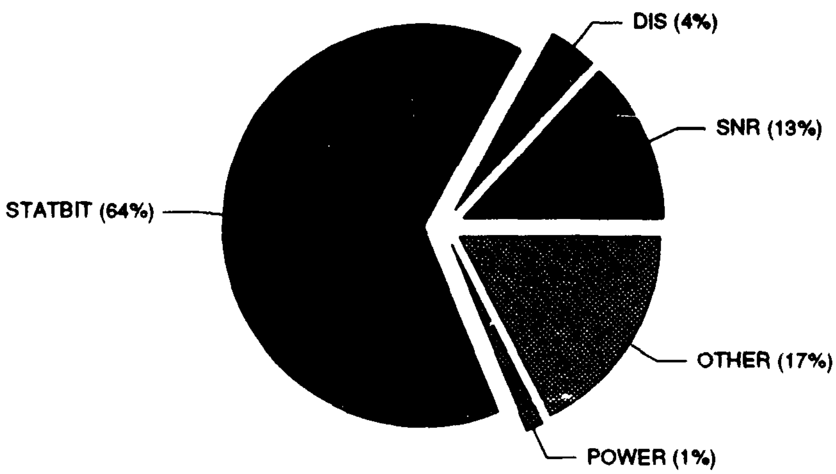
ALARMS RECORDED AT LAKEFRONT

(1986-1989)(14244 EVENTS)



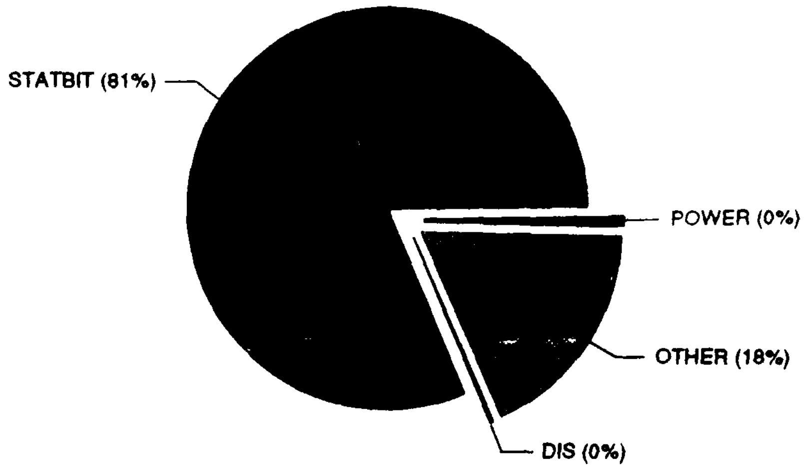
ALARMS RECORDED AT TSC

(1986-1989)(3277 EVENTS)



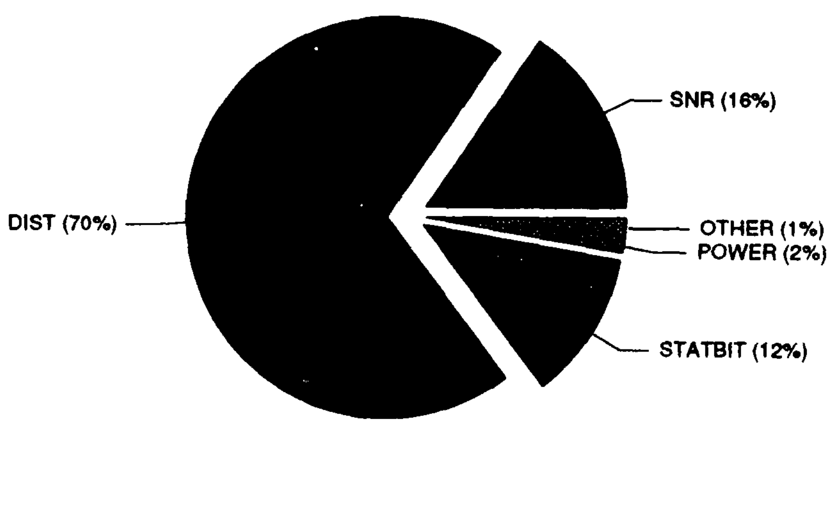
ALARMS RECORDED AT MILLVILLE

(1988-1989)(1662 EVENTS)



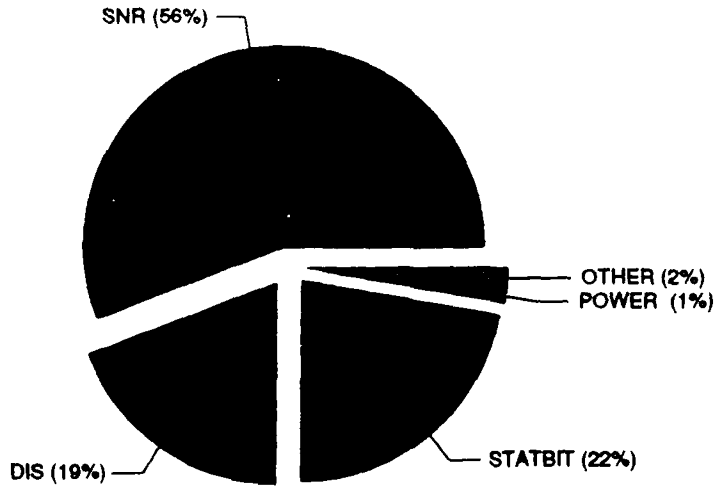
ALARMS RECORDED AT MCNARY

(1986-1987)(3875 EVENTS)



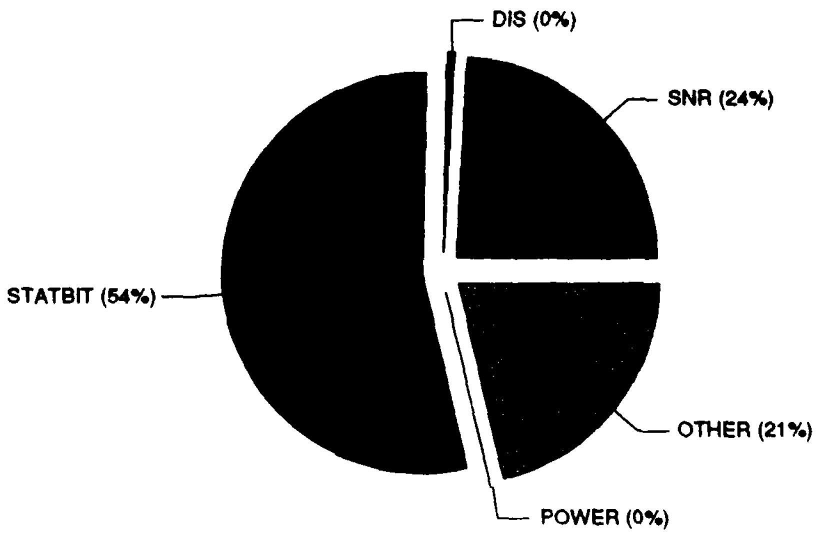
ALARMS RECORDED AT PORTLAND

(1986-1989)(17692 EVENTS)



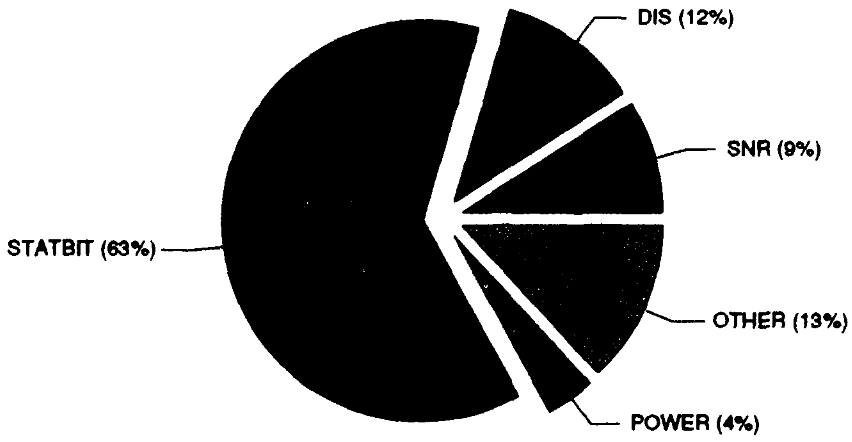
ALARMS RECORDED AT SOUTH BEND

(1988-1989)(1698 EVENTS)



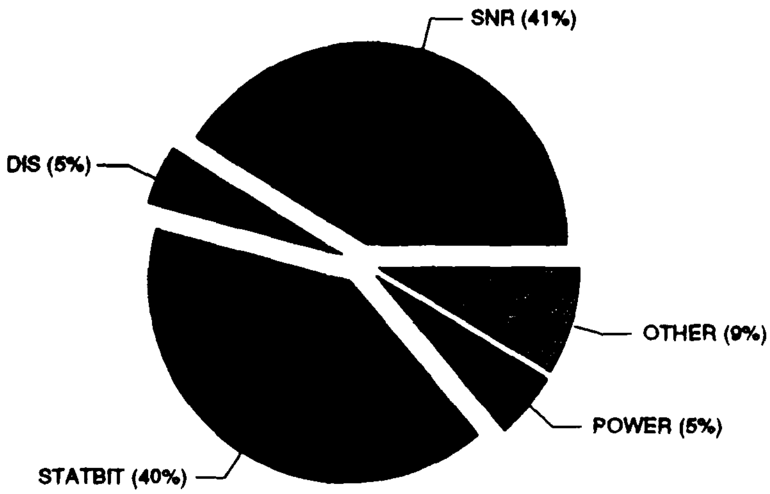
ALARMS RECORDED AT BURLINGTON

(1986-1989)(5215 EVENTS)



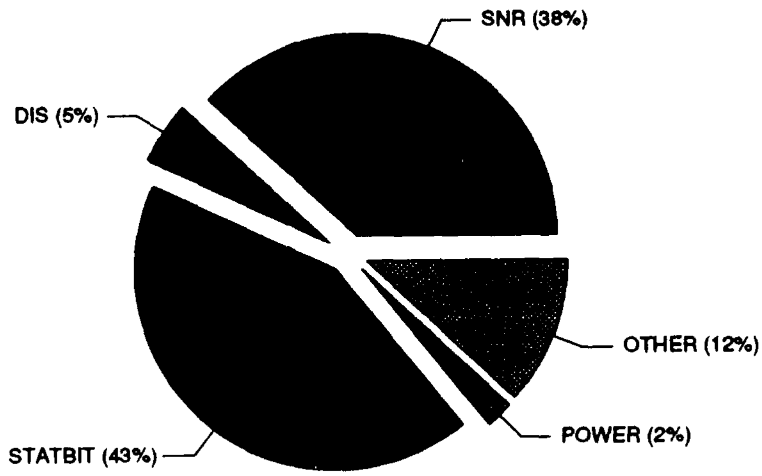
ALARMS RECORDED AT OHIO STATE

(1986-1989)(11810 EVENTS)



ALARMS RECORDED AT HANSCOM

(1986-1987)(10618 EVENTS)

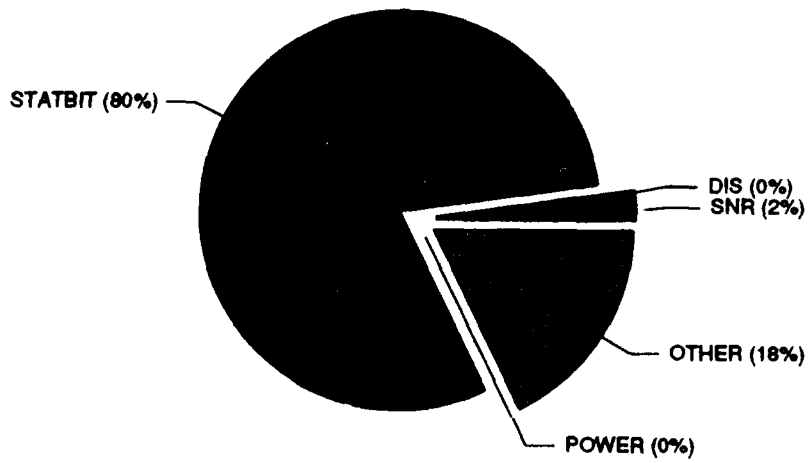


APPENDIX I

EIP ALARM TYPES, BY AIRPORT (1989)

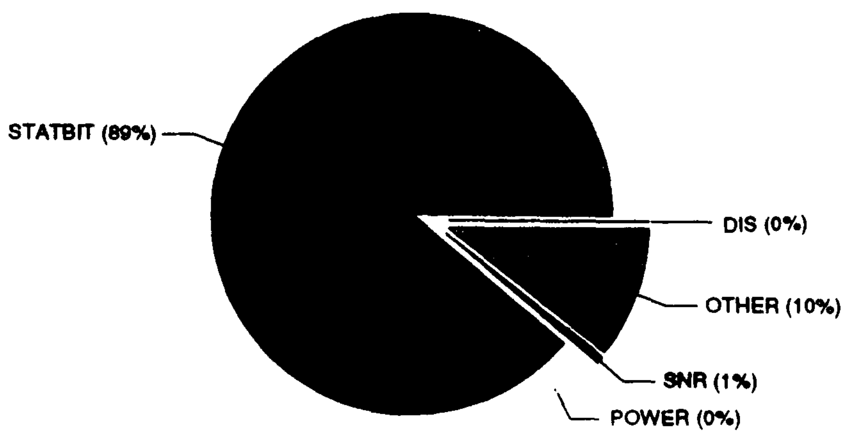
ALARMS RECORDED AT MANASSAS

1989 (798 EVENTS)



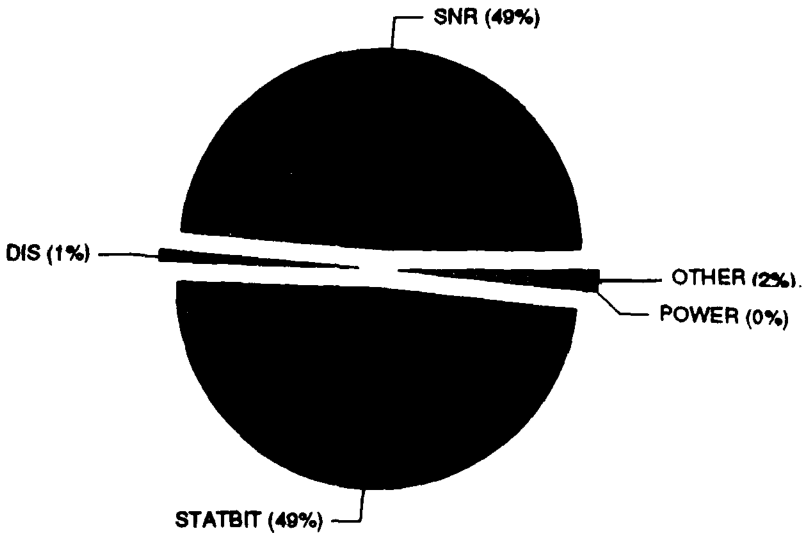
ALARMS RECORDED AT MILLVILLE

1989 (710 EVENTS)



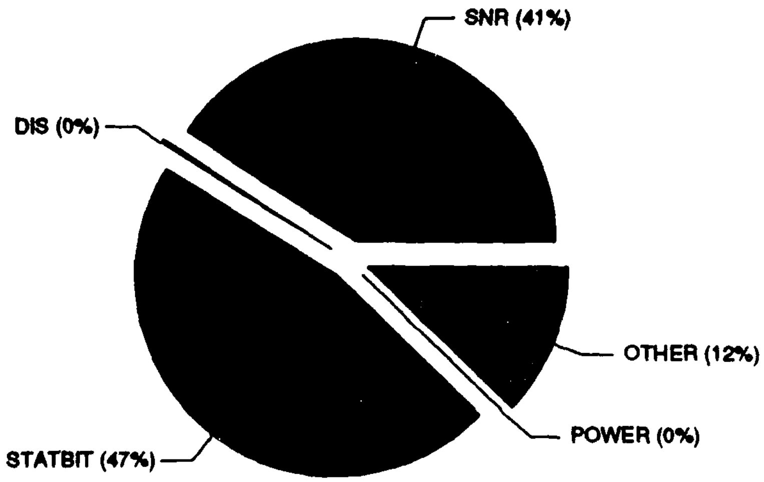
ALARMS RECORDED AT PORTLAND

1989 (846 EVENTS)



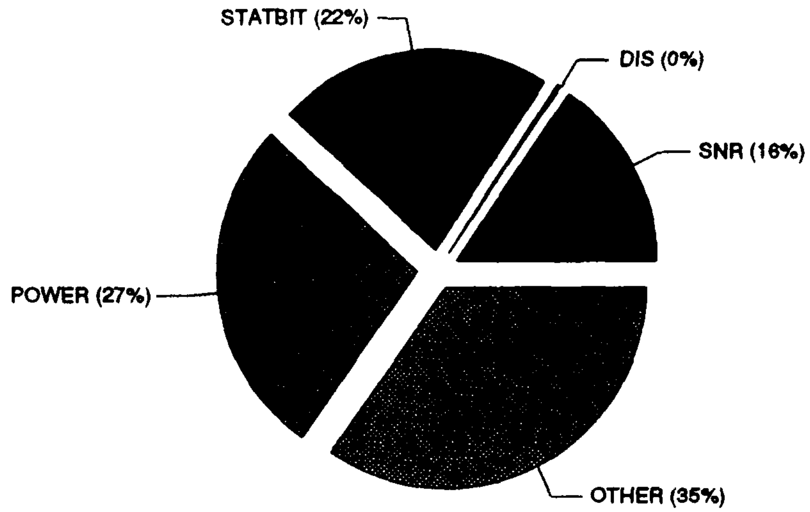
ALARMS RECORDED AT SOUTH BEND

1989 (912 EVENTS)



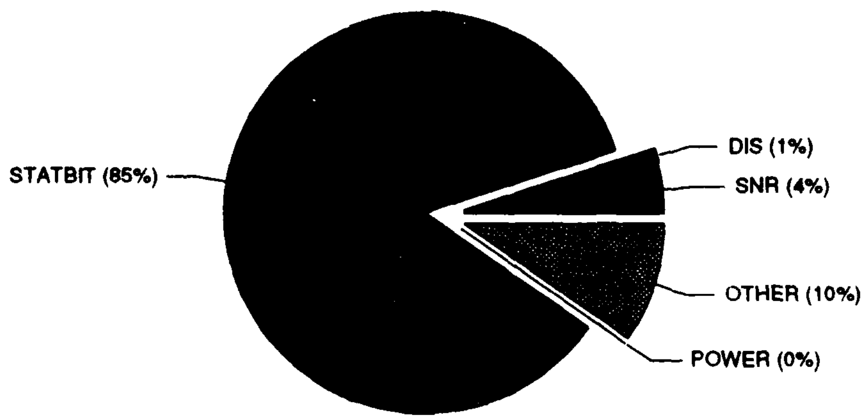
ALARMS RECORDED AT ORLANDO

1989 (901 EVENTS)



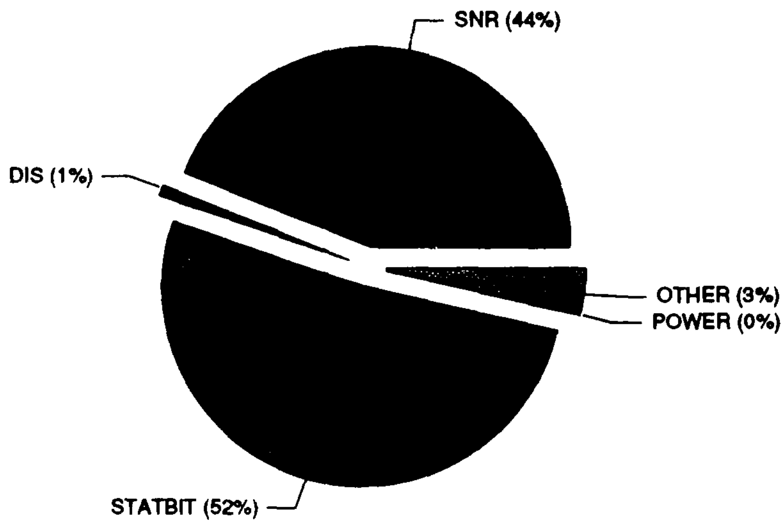
ALARMS RECORDED AT BURLINGTON

1989 (726 EVENTS)



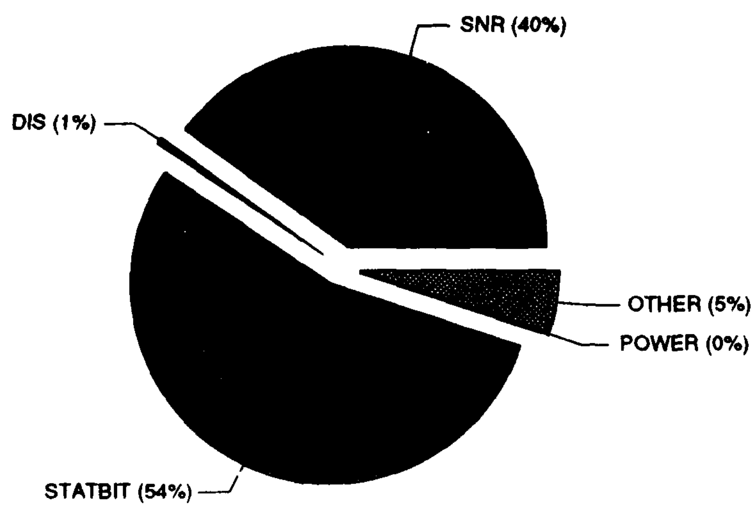
ALARMS RECORDED AT LAKEFRONT

1989 (1053 EVENTS)



ALARMS RECORDED AT OHIO STATE

1989 (1127 EVENTS)



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